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Final report on interrelationships between chemical, physical and biological conditions of the waters of Las Vegas Bay of Lake Mead

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FINAL REPORT

ON

"INTERRELATIONSHIPS BETWEEN CHEMICAL, PHYSICAL AND BIOLOGICAL CONDITIONS OF THE WATERS OF LAS VEGAS BAY OF LAKE MEAD"

TO

Las Vegas Valley Water District
3700 West Charleston Boulevard
Las Vegas, Nevada 89102

FROM

The University of Nevada, Las Vegas
Las Vegas, Nevada 89154

Dr. James E. Deacon
Dr. Richard W. Tew
Department of Biological Sciences

PERSONNEL

This study was directed by Doctors James E. Deacon and Richard W. Tew. Field supervision, as well as a considerable quantity of literature review and data reduction and evaluation, was under the direction of Mr. Larry Paulson.

Identification and counting of algae was conducted primarily by Mrs. Toni Heiner. Other personnel involved in various aspects of the study include: Al Espinosa, Jack Fisher, Karen Harville, Scott Miller, and Charles Minckley.

INTRODUCTION

This program was a status study of the interaction between Las Vegas Wash, an enriched stream, and Las Vegas Bay, a wedge shaped arm of one of the world's deeper reservoirs. The program centered primarily on identification and counting of planktonic algae from several points in Las Vegas Bay. Additional work on nutrient enrichment of water samples was conducted to aid in interpretation of algal distribution related to nutrient input. Examination of a variety of physical, chemical, and biological parameters, both at many surface points in the bay, as well as in vertical profile, was also accomplished and further aided interpretation of nutrient cycling, sources of nutrient input and other limnological events commonly associated with the process of eutrophication. One copy of data is provided as an appendix to this report. Other copies are available on request.

An intensive sampling program has been the core of the project. Fifteen stations were located to provide an "early warning" network for detection of directed movement of water bodies or strata in the bay, reliability in evaluation of surface plankton distributions, and reference points for exploitation of unanticipated opportunities. These stations were visited approximately weekly during the contract period for plankton samples to evaluate biologically-induced or biologically-responsive changes as cumulative indices of the chemical status of the system. Evaluation of results was

aided by determinations of depth profiles of the standard limnological parameters: temperature, a measure of the degree of stratification or mixing of a lake, oxygen, pH and oxidation-reduction potential. Conductivity, to identify isothermal yet saline discontinuities and especially the location of the flow from Las Vegas Wash, was also measured.

Colonies or unicellular plankton were counted to determine distribution versus time over the bay surface. Distribution and density, rather than productivity, was of primary interest; although evidence for growth or accumulation at given points was also obtained.

Chemical analyses for principal anions and cations (such as sulfate, chloride, sodium and potassium) and major nutrients (such as phosphate) were performed in cooperation with Desert Research Institute and Environmental Protection Agency. Counts of total and coliform bacteria were made on samples from vertical profiles at various times to establish the reason for the pattern of oxygen depletion found.

METHODS

Sampling Stations

The locations of 16 sampling stations appear in Figure 1. It is convenient to group these stations as follows: a) Station 16, Las Vegas Wash; b) Stations 1, 2 and 3, inner bay; c) Stations 4, 5, 6 and 7, middle bay; d) Stations 8, 9, 10, 11, 12, 13 and 14, outer bay; and e) Station 15, water intake tower.

Although the designations "inner", "middle", and "outer" bay were intended as a convenience, they are actually justified by subsurface topography.

Stations 4 and 8 are center channel stations at points of transition from inner-to-middle and middle-to-outer bay.

Stations 1, 2, 3, 4, 8, 11 and 14 are located at deepest points, the remainder of the stations were located by dividing the bay into numbered squares, and selecting from a table of random numbers.

Buoys located at each station provide boat anchorages and prevent hit or miss sampling.

Phytoplankton Assay

The existence of small algal populations necessitated concentration by a procedure resulting in the least possible damage to the largest percentage of the population. A filtration procedure seemed most suitable since centrifugation produced intolerable damage to a number of organisms comprising

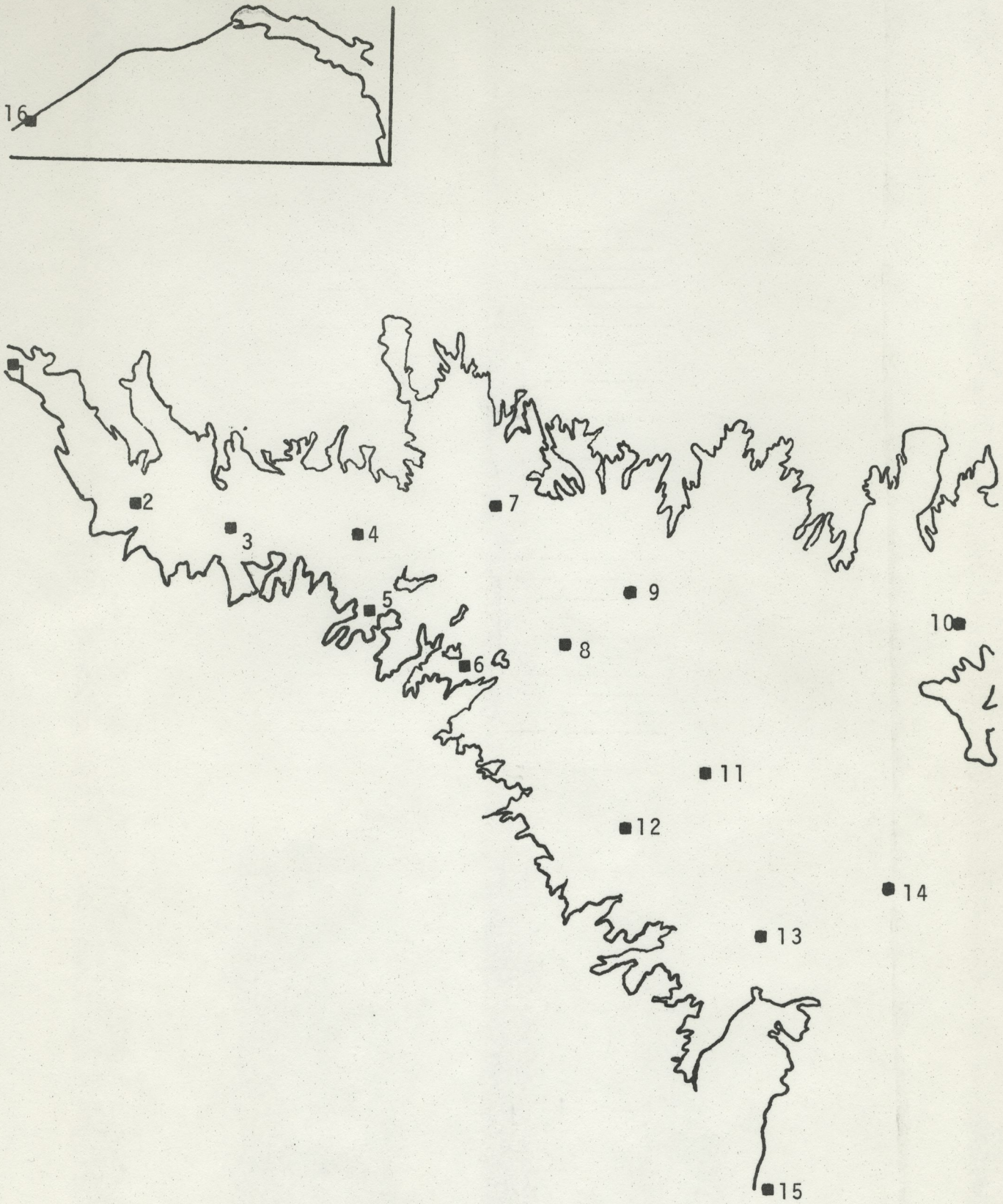


Figure 1. Location of sampling stations in Las Vegas Bay, Lake Mead, Nevada.

a large fraction of the total count. For instance dinoflagellates may be ruptured by stress as mild as merely tapping a cover slip. Therefore, plankton methods involved: 1) identification in intact samples if organism concentrations are sufficiently high, 2) identification, and determination of percentage alive, in filtered aliquots, 3) counting of samples prepared by the Ferguson-Wood method (see below).

Although colonies and unicellular forms were enumerated on an equal basis, the number of cells per colony were determined for genera comprising a dominant fraction of the phytoplankton.

Preparation for identification and determination of live/dead ratios was done by filtration of a 200 ml aliquot gently through a filter until only approximately 2 ml liquid volume remained above the filter. This liquid is used via capillary pipet to wash the organisms off the filter and into suspension. The suspension is then used as a concentrated sample for identification. Representative concentrates were preserved in chromic acid for future reference.

The Ferguson-Wood method involves filtration of a 200 ml (or suitable) aliquot of sample through a millipore filter. The filter is dried and cleared with immersion oil and 1/4 of the filter is mounted on a slide under a coverslip. A permanent mount results. The 200 ml aliquots were removed from a sample collected by combining three separate one liter sub-samples collected from the same site. Statistical analysis

of several samples collected from one location in this manner indicated that significant differences did not exist between samples. Collection of fewer sub-samples on the other hand indicated considerable variability. We therefore concluded that collection of three separate one liter sub-samples provided an adequate sample of the phytoplankton at that location and time. Tests for significant differences in distribution of phytoplankton on each quarter of the same filter also indicated that differences are not statistically significant. The statistical procedures used to arrive at the above conclusions are discussed in a later section of this report.

Nutrient Enrichment

Nutrient enrichment studies were conducted by adding 1 ml of a nutrient solution to 99 ml of water taken from Stations 1 and 14. The solutions were mixed according to recommendations made by Gerloff (personal communication). These enriched samples of lake water were incubated at ambient temperature for two weeks under 100 fc illumination. The incubated samples were then thoroughly mixed, all algae scraped from the sides and the mixed sample read on a B and L Spectronic 20 at a wavelength of 525 mu. A control without nutrients added was used to assess whether or not any additional growth of algae occurred that would not have occurred without nutrient enrichment. In a few cases there was less growth in some samples with certain nutrients added than occurred in the control.

Usually all test samples showed more growth than occurred in the control however.

Chlorophyll Analysis

Concentrations of chlorophylls A, B, C, and astacin and non-astacin carotenoids were measured by acetone extraction of pigments from material concentrated on a millipore filter. Samples were collected and filtered as previously described under phytoplankton methods. Pigment concentrations were estimated by using formulae presented by Parsons and Strickland (1968) to convert readings from a B and L Spectronic 20 to pigment concentrations in mg/m^3. Corrections for phaeophytin were not included in the extraction technique.

Physical Data

Data on temperature, conductivity, D.O., pH, and redox potential were measured at 5 meter intervals in a vertical profile at each station with a Hydrolab. This unit is calibrated monthly, or when peculiar readings are encountered while sampling. A record is compiled from each calibration check, should questions arise concerning the accuracy of the unit. The procedures for calibration checks are outlined as follows for each parameter measured.

Oxygen calibration is checked by one of three methods: 1) Winkler dissolved oxygen test, (this is the test most commonly used) 2) comparison with O_2 solubility tables, 3) air calibration using a special adapter developed by Hydrolab Corporation

specifically for oxygen calibration.

The temperature probe is calibrated against a precision hand thermometer (U.S. Bureau of Standards Calibration). Two solutions are used, one relatively hot, the other cold.

The pH electrodes are standardized with two standard buffer solutions (pH 4. and pH 8.). In addition to this, a portion of the water in which the Hydrolab sond unit is submersed is removed and checked against a Corning Model 12 pH meter. This is then compared to the reading of the Hydrolab Unit for that water.

To calibrate the conductivity probe salt solutions were prepared encompassing the range of conductivities generally encountered in Las Vegas Bay and Vegas Wash. The concentrations of these solutions are 500, 700, 900, 2,000, and 5,000 mg/l NaCl. A conversion from mg/l NaCl to micro mhos/cm is included below:

Conversion table from Hach Instruction Manual.

500 mg/l	=	1008 micro mhos/cm
700 mg/l	=	1410 micro mhos/cm
900 mg/l	=	1806 micro mhos/cm
2000 mg/l	=	3830 micro mhos/cm
5000 mg/l	=	9240 micro mhos/cm

Also, measured conductivities are compared with readings from a Hach Model 2200 conductivity meter.

After initial redox laboratory calibration is completed a calibration value is electronically locked into the unit. The calibration check is made by merely turning a dial on the instrument module to offset and the check is complete.

RESULTS

Statistical Analysis of Sampling Techniques

Introduction

Several procedures are currently available for enumerating freshwater phytoplankton. Lund et al. (1958) described an enumeration procedure using the inverted microscope. The technique is adequate statistically, but the necessary equipment is not always available at small institutions. Serfling (1949) and McAlice (1971) intensively evaluated the Sedgwick-Rafter method of sampling phytoplankton. Both concluded that the technique is somewhat inadequate for sampling nanno-plankton and populations of low density. A relatively new procedure of enumeration on membrane filters has been outlined by several researchers [McNabb (1960), Moore (1963), and Holmes (1969)]. The procedure has obvious advantages, as two of the authors point out; however the statistical validity is somewhat conflicting. McNabb (1960) maintains that the distribution of organisms on the filter is random and has good evidence to support it. Holmes (1969), however, showed that clumping may occur along the perimeter of the filter thereby necessitating the counting of the whole filter to insure accuracy. He too has statistical evidence supporting his conviction. Since both researchers used similar methods for preparing their samples, their opposing results are apparently due to methods of selecting areas of the filter for counting and differences in statistical

treatment of the data. In view of those findings, a more critical statistical review seemed justified prior to adopting the technique for an intensive evaluation of phytoplankton standing crop in Las Vegas Bay, Lake Mead, Nevada. The remainder of this paper is concerned with that review.

We wish to especially thank Ms. T. Heiner for counting the phytoplankton, F. A. Espinosa for his helpful suggestions and initial review of the manuscript and Drs. J. Kinneson and A. Goldman for their statistical advice and criticism.

Experimental Methods

The membrane filter procedure described by McNabb (1960), modified by Moore (1963) for permanent mounting on glass slides and further revised by Holmes (1969) to include dehydration of the filter with ethanol was used in this study. Preservatives were not used prior to filtration since samples were processed immediately after collection. The use of staining agents was circumvented by making identifications on concentrates of live material. No problem was encountered in recognizing organisms on the filters after the live identifications had been made. Further modifications and methods are discussed when appropriate in the context of the paper.

Experimental Design

The problem confronting any researcher dealing with an infinite population is: 1) selecting a representative sample,

and 2) extracting information from the sample that does not itself contribute substantial error. The multi-staged nature of phytoplankton sampling necessitates a design which meet these criteria not once, but several times.

In random sampling the error incurred at each stage of sampling is attributed to random error and not due to some bias introduced by the researcher (Cassie, 1971). Random sampling, however, often fails to yield results with a degree of precision required by the study (Cochran, 1963). This failure is probably attributable to the fact that markedly skewed distributions are common in phytoplankton sampling and can yield erroneous results if they are not accounted for (Cassie, 1963). Skewness, however, is more likely the result of incorrectly treating the sample, rather than reflecting the actual conditions of a population in the lake. Rather than simple random sampling, it seems that a systematic sampling approach is more likely to reduce variability and enhance precision of population estimates.

Our evaluation of the millipore filter method of enumerating phytoplankton began with an analysis of the distribution of organisms on the surface of the filter. Since the effective filtering area of a millipore filter is 960 mm^2, much too large to count in total, a method of counting the same portion of a filter in an identical manner for several samples had to be devised. Sectioning the filter into equal quadrats appeared to be a desirable modification. Fig. 2 depicts the device used

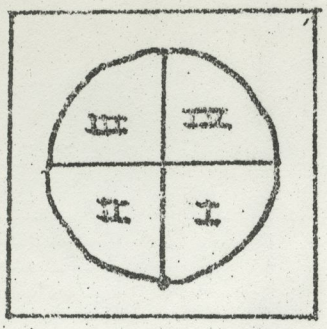


Figure 2.

Replicate of a 47mm millipore filter, etched into a plexiglass block, used to quarter the filters.

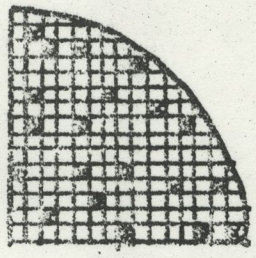


Figure 3.

Simulated quatrant showing twenty randomly selected counting fields.

X = fields 1-10
▨ = fields 11-20

to quarter a filter. It is merely a replica of a millipore filter (47 mm dia.) subdivided into four equal quadrats, etched into a plexiglass block. The dot between quads I and II is used to insure proper alignment of the filter prior to counting. Since the plain millipore filter is unmarked it was necessary to scribe a mark on the basal part of the filtering apparatus and place a corresponding pencil dot on the filter to guide alignment on the apparatus prior to filtration. This dot, visible after the filter has cleared, permits alignment with the mark on the plexiglass block. Each quad can then be sectioned and mounted under a 22 X 22 mm coverslip and secured to a standard glass slide. Mounting is not necessary but is advisable should later reference to a particular slide be desired.

Selecting counting fields from these quadrats is perhaps the most important operation in the design. Fig. 3 shows a quadrat subdivided into .25 mm squares (calibrated area of Whipple disc). Each square was numbered, i.e., 00, 01, 02. . . . . n, and fields were selected from a table of random numbers (Bliss, 1967). Initially, 20 fields were chosen and phytoplankton taxa were identified and counted in all 20 fields. This process was repeated for all four quadrats. Orientation to these randomly selected fields was made by using the microscope micrometer.

Sampling and Analysis

Three one-liter samples were collected in immediate

sequence from one location in Las Vegas Bay. Aliquots of 200 ml were filtered from each sample. During the course of a study by Koening et al. (1972) the 200 ml volume had been shown to be appropriate for achieving good distribution of phytoplankton on the millipore filter at densities occurring in Las Vegas Bay. Each slide was counted at 430X magnification. Fragments of filamentous phytoplankton were treated as one organism if they fell within the boundaries of the Whipple disc. Twenty fields were counted on each quadrat of the three samples, and an additional 20 were counted on one quadrat of sample I. These data were evaluated to determine variability of information from different counting fields, different quadrats of a filter and different samples from the same point in the lake.

Frequency Distributions on the Filters

Prior to statistical analyses it was desirable to gain some empirical knowledge of the frequency distribution of organisms on the filters. The total counts from 80 individual fields (20 from each of 4 quatrats) were used to construct frequency distributions for the three samples.

Cassie (1963) discussed several frequency distribution models and developed others by employing the log transformation. The most commonly used models are the discrete, probability distributions, binomial and poisson, and the corresponding continuous normal approximation. From a theoretical standpoint the probability distributions, binomial and poisson, are valuable

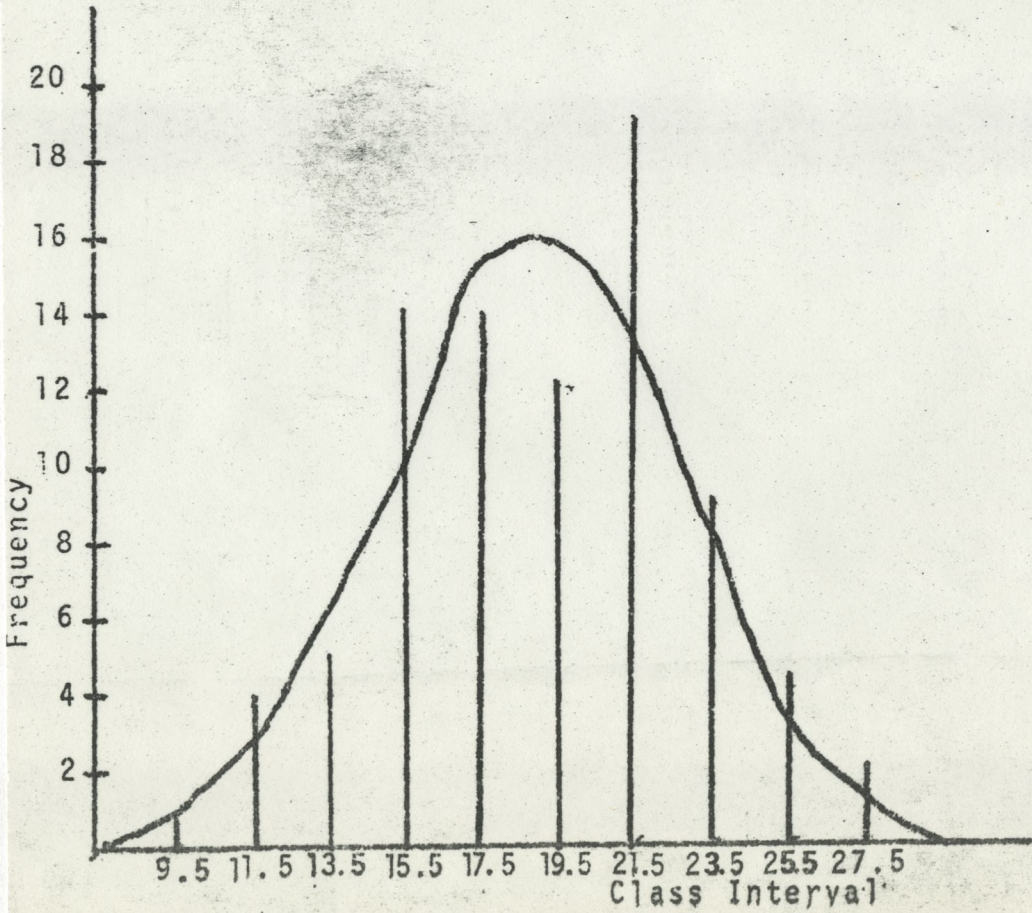
for describing the hypothetical distributions of organisms. They seem to be somewhat inadequate, however, for representing empirical data drawn from many observations. The binomial distributions is dependent upon two parameters: n, the number of trials and P, the probability of success. The number of trials (n) can be obtained from the data, but it is extremely difficult to a priori predict the probability (p) of one or many organisms falling onto one of several microscopic fields on the surface of the filter. This then somewhat restricts fitting the binomial distribution to our data. The poisson distribution, however, is dependent upon only one parameter $\mu = np$. Since the sample mean $\overline{X}$ is an unbiased estimation of the population mean (μ); a theoretical poisson distribution can be constructed, simply with a knowledge of the sample mean (Simpson and Roe, 1960). The poisson, however, can be used to approximate the binomial where n is large and p is small, but for greater increases in n irrespective of p the normal gives a better approximation (Simpson and Roe, 1960). The normal approximation to the binomial is best when $p = 0.5$, a symmetric distribution (Snedecor and Cochran, 1968). A remarkable symmetry existed in the observed frequencies when the data was secondarily grouped. Due to this symmetry, and the fact that our n (number of organisms per microscopic field) was large (>28 in the ungrouped category) and the difficulties in using the probability distributions; the normal curve was used to represent the data. To compensate for the discrete

nature of the data; secondary grouping, and the correction for continuity, breaking each interval at the midpoint, were employed (Simpson and Roe, 1963). The computation of the normal deviate then became (1) $Z = \frac{\mu-[\overline{X}-1/2]}{\sigma}$, and the theoretical normal frequencies were obtained by multiplying the normal probabilities by N = 80 (total observations). The Chi-square goodness-of-fit test was used to test for conformity between observed and theoretical normal frequencies. The acceptance criteria was $Px^2 > .05$ and $< .95$ with k-2 degrees of freedom, where k is the number of groups and 2 the number of constants (μ and σ) used to compute the normal deviate. A probability $Px^2 \geq .95$ is considered so good that the experiment should be checked for hidden bias, and a $Px^2 \leq .05$ is considered significant and warrants rejection of the hypothesis being tested (Bliss, 1967). We therefore established our acceptance region between these two critical values.

Figures 4, 5 and 6 show the observed and theoretical normal distributions. The Chi-square test reveals that the cummulative x^2 for each of the three samples had probabilities $Px^2 = .10-.50$, well within the range of the acceptance region. A satisfactory agreement therefore exists between observed and theoretical normal frequencies, and the normal approximation is a good representation of the data. The approximate normality of the sampling distribution is encouraging because it permits parametric statistical tests to be used to directly

Figure 4.

Observed and theoretical normal distribution for sample 1.



$W = 80$

$\mu = 18.875$

$\sigma = 3.969$

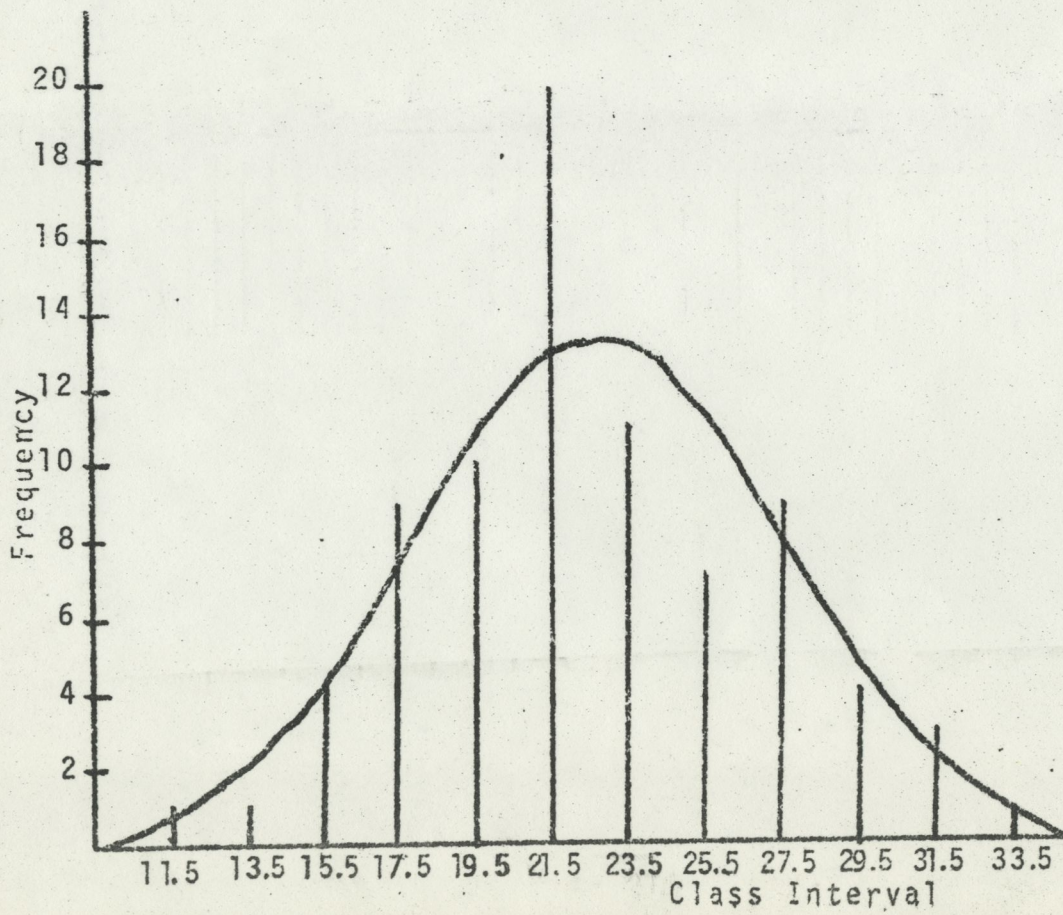
$\chi^2 = 6.9098$

$D.F = k-2 = 8$

$P(\chi^2) = .25 - .50$

Figure 5.

Observed and theoretical normal distribution for sample 2.



$N = 80$

$\mu = 22.625$

$\sigma = 4.729$

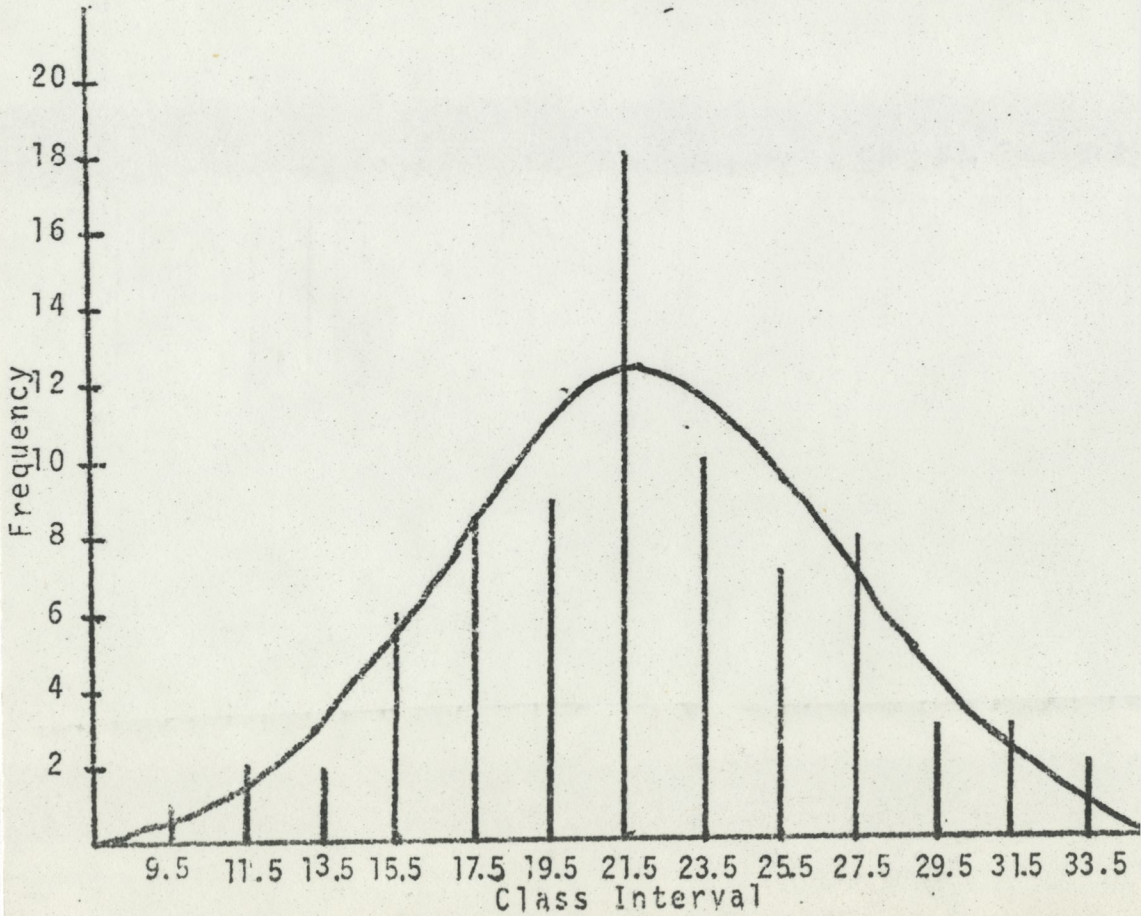
$\chi^2 = 7.0214$

$D.F = k-2 = 10$

$P(\chi^2) = .25 - .50$

Figure 6.

Observed and theoretical normal distribution for sample 3.



$N = 80$

$\mu = 21.950$

$\sigma = 5.121$

$\chi^2 = 6.675$

$D.F = k-2 = 10$

$P(\chi^2) = .10 - .25$

analyze for temporal and spatial differences in plankta populations.

Evaluation of Samples, Quadrats and Counts

A nested, three factor, random effects analysis of variance was used to determine the degree of variation associated with the sampling. The nested rather than factorial design was used because of the hierarchial nature of sampling. In the nested design the unique effects associated with a factor are restricted to one level within that factor (Winer, 1971). Fig. 7 reveals the identity of the factors and levels of each. Since each factor is treated independently of the others, the nested design with factors B and C nested under factor A, is the desired model.

The computational procedures are similar for the factorial and nested designs, however, they differ in the construction of the A.O.V. table. It is possible to obtain a nested design from a factorial by using the fully-crossed factorial equivalent outlined by Dixon (1968, p. 504). A method for calculating the nested d.f. from a factorial was adopted from Winer (1971). These sources permit use of factorial computer programs, for which most three-way analyses are intended, to obtain valid nested designs.

The results of the nested three factor experiment for data discussed above are outlined in Table 1. The analysis reveals that a significant difference exists between the samples.

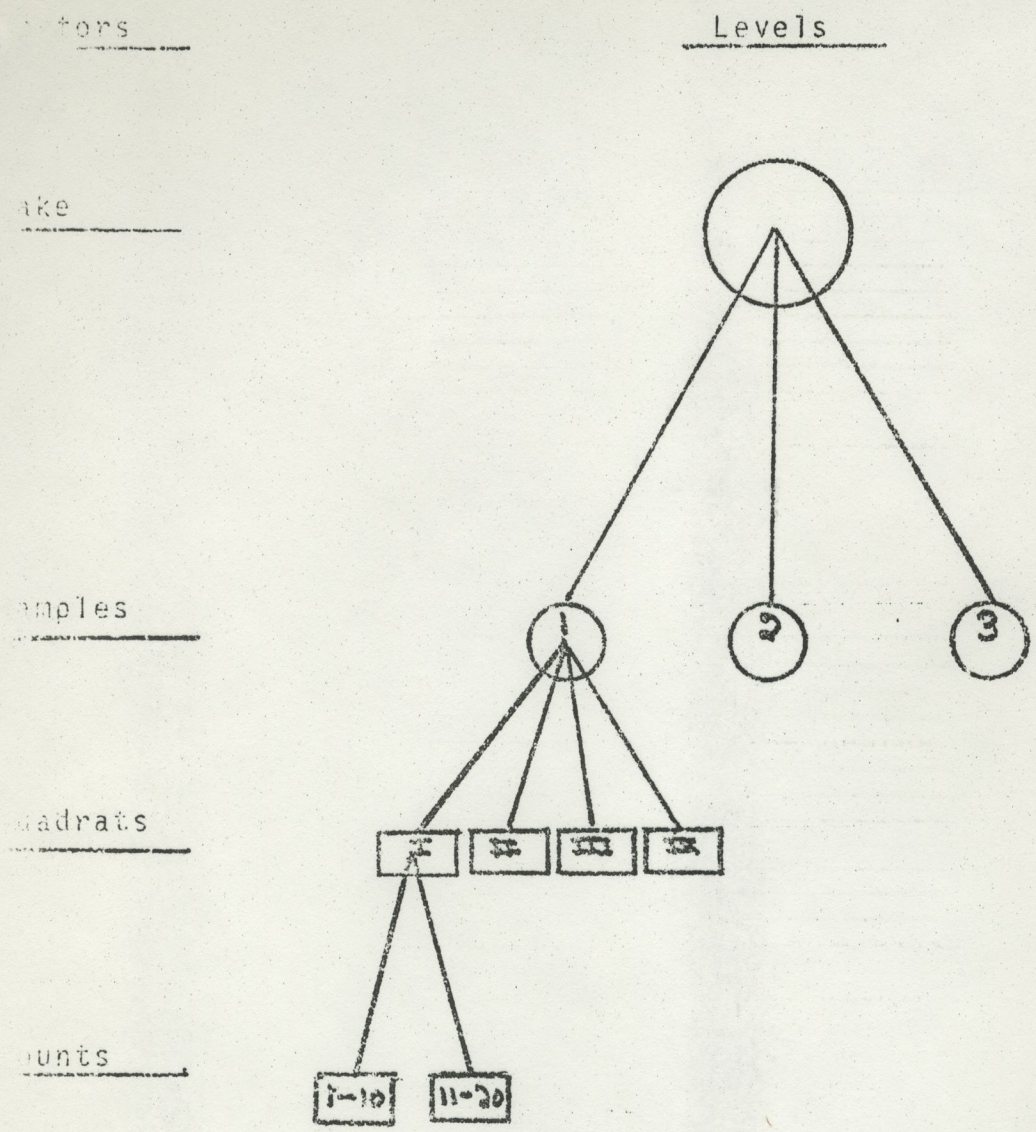


Figure 7.

Schematic representation of the hierarchichal sampling program employed for the statistical evaluation.

Table 1. Nested A.O.V. for samples, quadrants, and counts. Computations based on raw counts from fields 1-10, and 11-20.

Source	D.F.	SS	MS	F
Samples	2	577.633	288.817	12.258**
Quads.	9	279.000	31.000	1.311
Counts	12	361.499	30.125	1.274
Error	216	5105.803	23.638	
Total	239	6323.97		

**Significant at 95%

The methods of treating each sample through are certainly satisfactory as shown by the very homogeneous MS and low F-Ratio for quads and counts. The implications of the analysis are that only one quadrat need be examined from each filter, and only 10 counts are required on that quadrat to adequately represent the sample. The remaining problem was to resolve the large discrepancy between samples, and to determine if any difference existed between aliquots of the same sample.

We reasoned that if unacceptable variability existed between individual samples taken in quick succession at the same location, integration of multiple single samples into a single integrated sample would likely reduce that variability. To test this hypothesis three more samples were collected from the same location in Las Vegas Bay; these consisted of three 1-liter sub-samples integrated to form one larger sample. The same enumeration procedure was followed, but each sample was sub-sampled (200 ml aliquots) twice and only one quadrant was examined from each filter. Even though no significant difference existed between counts in the previous series of samples, this factor was retained in the experiment since it allowed fractional replication of counting fields. This kept the number of observations per cell in the A.O.V. at the reasonable level of 10 rather than 20.

Another nested A.O.V. was designed with the following factors: a) samples (3 levels), b) sub-samples (2 levels), c) counts (2 levels). The results of that analysis, summarized

in Table 2, show no significant F-values in any of the factors. The hypothesis that integration of samples decreases variability is therefore confirmed. The analysis also indicates that only one sub-sample is needed to adequately evaluate each sample.

Although no significant difference was detected between the counts at 10 and 20 fields for either the first or second set of samples; this did not imply that 20 fields were adequate. To determine an adequate number of counting fields, a species area curve was constructed from the 40 field counts made on one quadrat of a sample. Forty fields were considered maximum since 90-95% of the species were accounted for by that level. However, since our concern was not to determine the percentage of species detected, but rather to estimate the mean number of plankton present with the minimum reliable effort, another test was necessary. Results of a one factor A.O.V. are presented in Table 3. Once again no significant difference was detected; suggesting that the mean number of algae counted in 10 fields is similar to that in 40 fields.

Discussion

The systematic, rather than random sampling program appears to have distinct advantages when phytoplankton sampling with membrane filters. An exact analysis of error on the surface of the filter required that precisely the same procedure be used on each sample. When error induced variability was encountered one must be able to identify the source and if possible

Table 2. Nested A.O.V. for samples, subsamples, and counts. Computations based on raw counts from fields 1-10, and 11-20.

Source	D.F.	SS	MS	F
Samples	2	46.550	23.275	2.511
Subsamples	3	72.017	24.006	2.580
Counts	6	48.650	8.108	0.814
Error	108	1001.100	9.269	
Total	119	1168.317		

Table 3. One factor A.O.V. that evaluates counting fields. Computations based on raw counts from fields 1-10, 11-20, 21-30, and 31-40.

Source	D.F.	SS	MS	F
Counts	3	88.900	29.633	1.506
Error	36	708.600	19.683	
Total	39	707.500		

to reduce that error. Simple random sampling does not allow such reduction in error; it only gives an initial estimate. A systematic program developed from a pilot evaluation where sampling units are replicated not only identifies error sources but permits reducing error by procedural modifications. The systematic approach, however, invariably results in higher labor demands and care must be taken not to belabor the sampling program. The modifications we incorporated into the membrane filter technique, mainly: 1) increasing the sample volume, 2) sectioning the filter, and 3) establishing a uniform counting procedure resulted in some additional labor demands. These, however, are considered insignificant when one considers the increased precision of the sampling program.

The sampling program developed from this evaluation requires that: 1) three one-liter sub-samples from a single point in the lake be collected and combined into a single sample; 2) one, two hundred ml aliquot be filtered from each sample; 3) one quadrat be examined from each filter; and 4) ten microscopic fields be counted from each quadrat.

The sampling program we outlined is appropriate for plankton densities encountered in Las Vegas Bay. However, the technique can be applied to any population by varying the volume of lake samples and sub-sample aliquots.

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Interrelationships Between Biological, Physical and Chemical Conditions

Las Vegas Bay has four seasons easily distinguished by the number, kind, and relative proportions of the phytoplankton, and by physical factors. These seasons are: 1) The Mixing Condition (from extinction of the thermocline 7 December 1971 until 1 March 1972), 2) Spring Oligotrophy (to 1 May), 3) Summer Plankton Maxima (to 15 September), and 4) Return to the Mixing Condition.

For convenience in discussion, and with considerable justification from the data, three regions of the bay may be defined. These were: 1) Inner Bay, Stations 1, 2, and 3; 2) Middle Bay, Stations 4, 5, 6, and 7; and 3) Outer Bay, Stations 8 through 14. Stations 1, 2, 3, 4, 8, 11, and 14 were "center channel" stations.

Station 15 was in the main body of the lake near the LVVWD water intake, and Station 16 in Las Vegas Wash where it flows under the North Shore Road Bridge.

The Mixing Condition

In the following text, physical factors are discussed first to emphasize the role of winter circulation in depleting the bay of accumulated nutrients, with net nutrient loss resulting from continual dilution of the lake (in equilibrium with the bay) by the Colorado River.

Physical Factors

Temperatures

Temperature measurements taken from the middle and outer bay from 7 December 1971 to 1 March 1972 fulfilled the classical definition of a lake in the circulating condition. Temperatures were effectively isothermal from top to bottom. Occasionally, variations of 0.5° or less from an average was evident in a water column. Depressed temperatures were found most often, but not always, (Station 6, 17 Jan.; Station 11, 24 Jan.; Station 13, 7 Feb.) just above bottom, and had no consistent correlation with higher or lower conductivity, or with other factors. Evidence for surface heating was likewise transitory, localized, and inconsistent.

The use of the word "effectively" to describe isothermal conditions must be qualified, since energy transfer within the bay is implied, and factors required to compute transfer of heat and momentum unknown. "Effectively", then, is best used in a negative sense to indicate that persistent discontinuities (stratification) did not develop.

An idea of the vigor of mixing can, however, be gained through consideration of thermal events in the inner bay. The data are in Table 4. Interpretation must be conditional since results were not continuously recorded.

Note that the temperature of the wash is consistently and markedly lower than the temperature of the bay in general, (although fluctuations during the day are unknown) and that water

from the wash, as indicated by the lower temperatures, tended to flow along the bottom of the channel at Station 1.

Consideration of temperatures of the water in the wash, and surface temperatures and gradients at Stations 1 and 2 from one sampling period to another indicate that the degree of mixing in the inner bay is variable but always pronounced by the time wash water reaches Station 2. On only one date (31 Jan.), when the conductivity in the wash was especially high, and wash temperatures low, could an exceptionally low temperature, 9.5°, be found above bottom at Station 4. On this date the above bottom temperature at Station 3 was paradoxically 10°.

A mathematical treatment of the work involved in mixing would allow expression of the effects of circulation in the inner bay to be expressed in quantitative form. If flow rates and flow volumes of the wash, other energy exchange-related functions, such as radiation and wind effects, and dilution volumes were known, a valuable model for density-temperature related stream-lake interactions could be proposed and verified.

The final date for the mixing condition, 1 March, was estimated by evidence for stratification on that date. Actually, if subsequent hypolimnion temperatures are considered to be similar to temperatures in the water column before stratification, the final date for mixing could be advanced by a week or two. Perhaps the last two weeks in February could be considered an interim period.

Table 4. Temperature versus depth at Stations 16, 1, and 2 during the mixing condition in Las Vegas Bay.

	Station and Depth, Meters								
Station	16	1				2			
Depth (M)	0	0	1	2	3	0	5	10	13
17 Jan.	5	10.5	10.25	9.5	6.0	11.0	10.5	10.5	10.5
24 Jan.	5.5	10.5	10.0	9.95	6.25	11.0	10.5	10.5	10.5
31 Jan.	2.5	8.5	8.3	7.5	4.0	10.0	9.95	9.5	9.5
1 Feb.	5.5	7.5	7.5	7.5	4.0				
2 Feb.	3.5	9.0	8.5	7.5	3.5	10.0	90.0	9.5	9.5
7 Feb.	7.5	10.5	10.5	10.5	7.5	10.5	10.5	10.5	10.0
14 Feb.	6.5	11.0	10.5	10.5	8.5	11.0	10.5	10.5	9.5

Oxygen

Oxygen profiles tended to be essentially uniform from top to bottom, hence, orthograde. Concentrations of 10 ppm or higher were consistently noted in the inner bay. When the data for the outer bay are plotted carefully, it becomes evident that the word "essentially" must again be qualified. Slight negative heterograde or clinograde situations appear in a transitory way from station to station and from one sampling date to another.

For example, on 17 January, oxygen concentrations below 10 ppm were noted as follows:

Station 4: 9.95 at 15 and 20 meters

Station 8: 9.7 at 15-40 meters

Station 10: 9.7-9.6 at 30-49 meters

Station 11: 9.9-9.7 at 10-33 meters

Station 13: 9.8 at 30-40 meters

Stations 14 and 15: 9.8 decreasing to 9.6 below 10 meters

At other stations on this date, concentrations were above 10 ppm.

On 24 January oxygen concentrations below 10 ppm were measured only at the following stations at depths indicated.

Station 9: 9.9 at 25-26 meters

Station 10: 9.9-9.7 at 15-48 meters

Station 11: 9.95-9.4 at 15-75 meters

Station 13: 9.9-9.8 at 15-30 meters

Stations 14 and 15: Same as Station 13

The pattern of decreased oxygen concentrations seemed to move out into the bay in January, and back in as far as Station 4 in February.

Oxygen variations were not correlated with increases or decreases in temperature, conductivity, or pH.

Hydrogen Ion

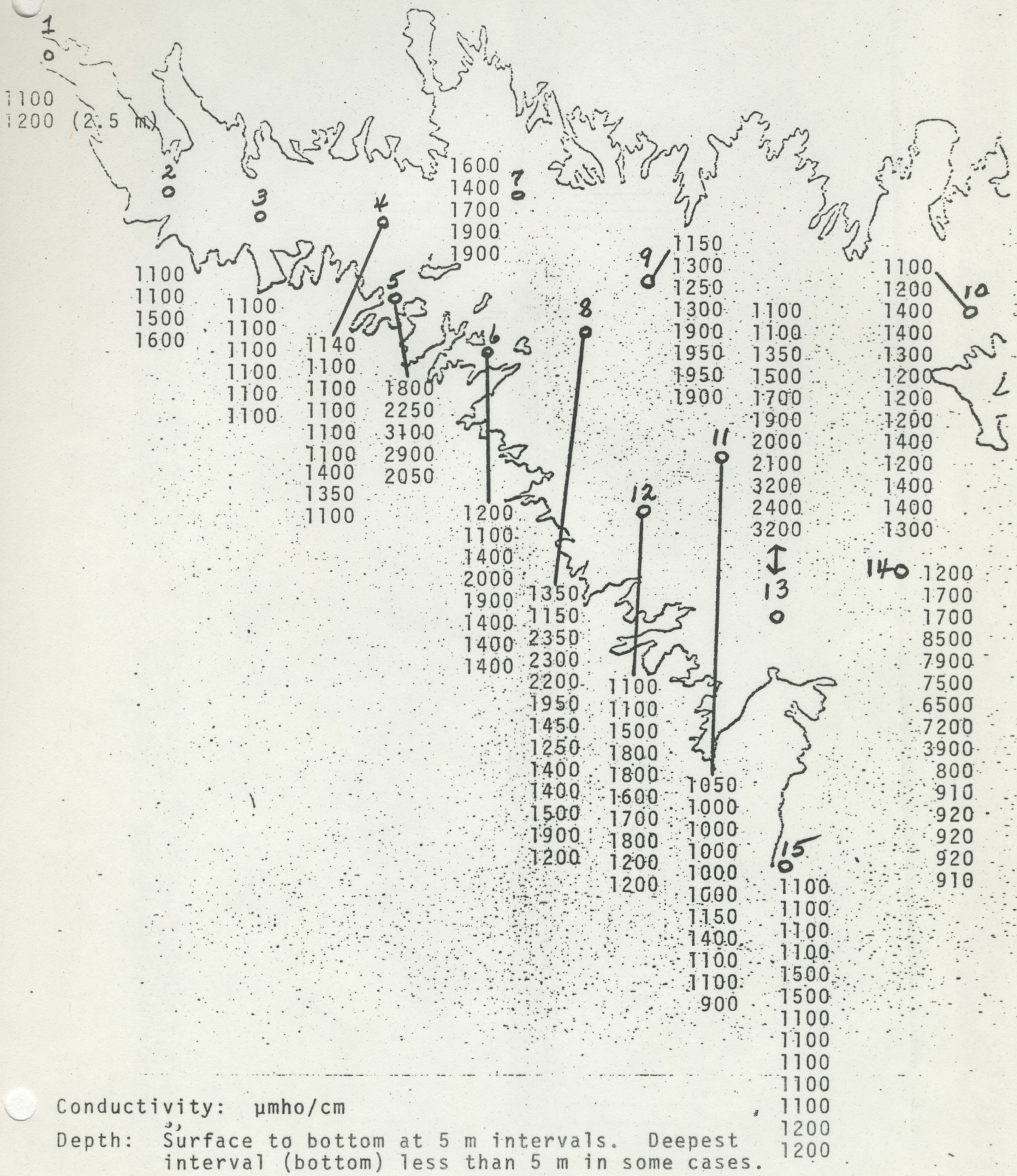
The pH data presented a much more uniform picture. Exceptions were: 1) On 1 January at Station 15, pH was 8.25 from the surface to 45 meters (bottom). At 50, 55, and 60 meters, pH was 9, 8.9, and 8.4 respectively. This condition disappeared by 17 January, when pH throughout the bay was 8.2 to 8.3.

In February, a trend toward somewhat lower pH appeared, especially in the middle bay. On 7 February, pH dropped below 8 at Station 4 between 15 and 35 meters, and was 7.9 from surface to bottom at Station 7. On 14 February a uniform pH of 7.9 was noted at Stations 4, 6, 7, and 8.

Conductivity

Conductivity data are given in Tables 5 through 10. Several transient conductivity discontinuities appeared in the middle and outer bay during January. When the data were plotted versus depth and compared from station to station, it appeared that these discontinuities represented isothermal bodies of water, more or less saline than most of the water in the bay by an average value of 1000-2000 μmhl/cm. This

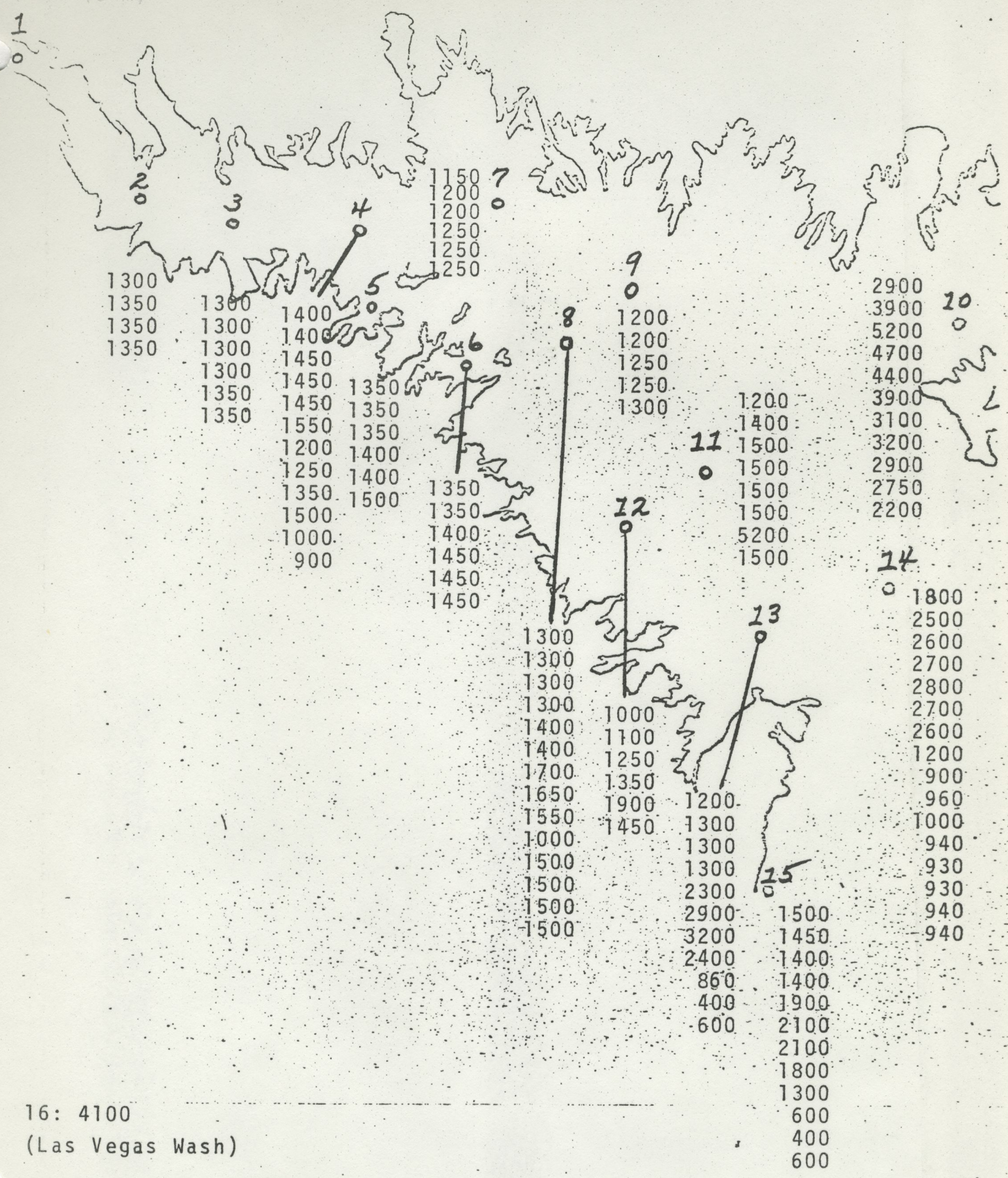
Table 5. Conductivity in Las Vegas Bay, 10 January 1972.



Conductivity: µmho/cm

Depth: Surface to bottom at 5 m intervals. Deepest interval (bottom) less than 5 m in some cases.

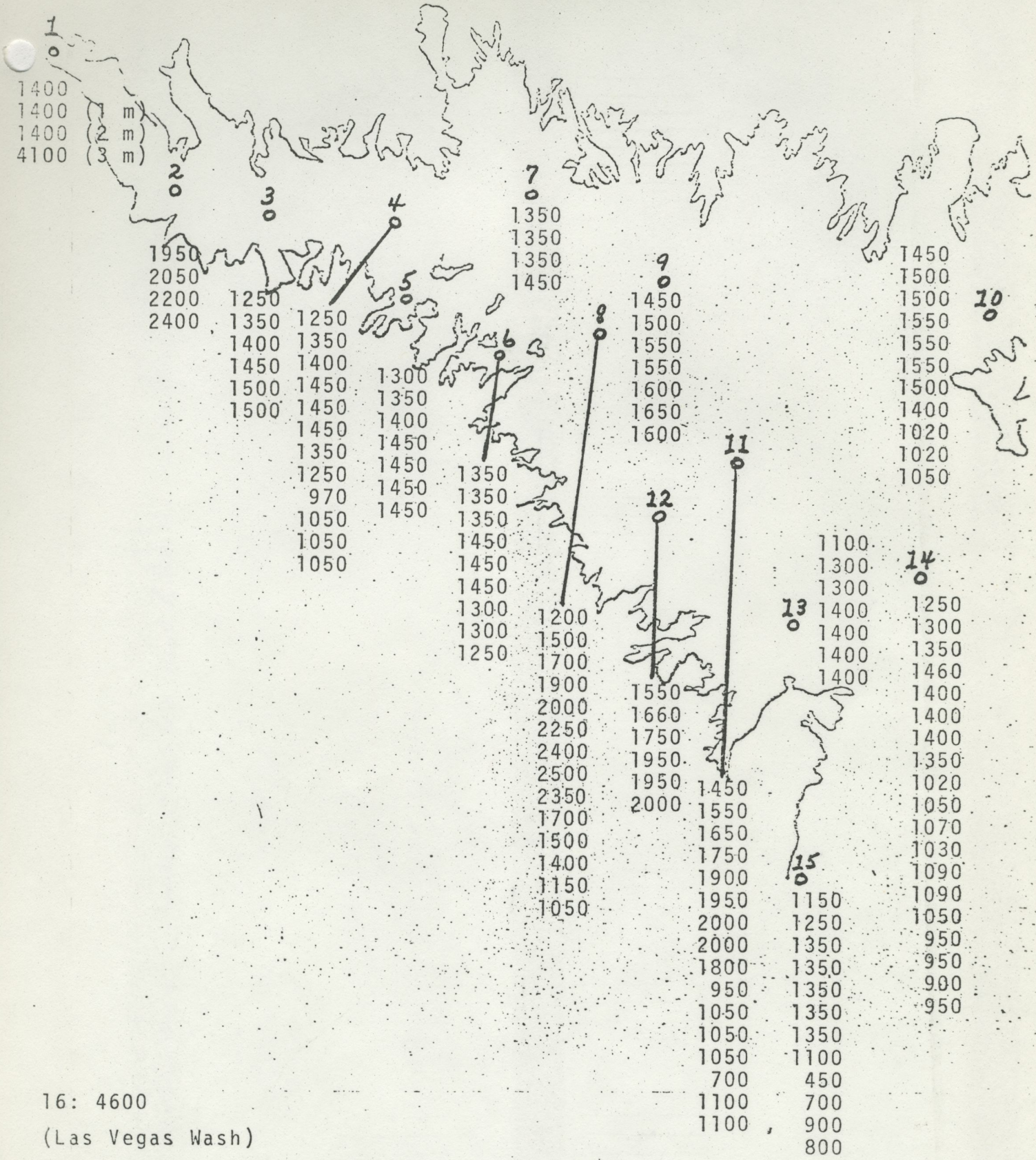
Table 6. Conductivity in Las Vegas Bay, 17 January 1972.



Conductivity: µmho/cm

Depth: Surface to bottom at 5 meter intervals. Deepest interval (bottom) less than 5 m at some stations.

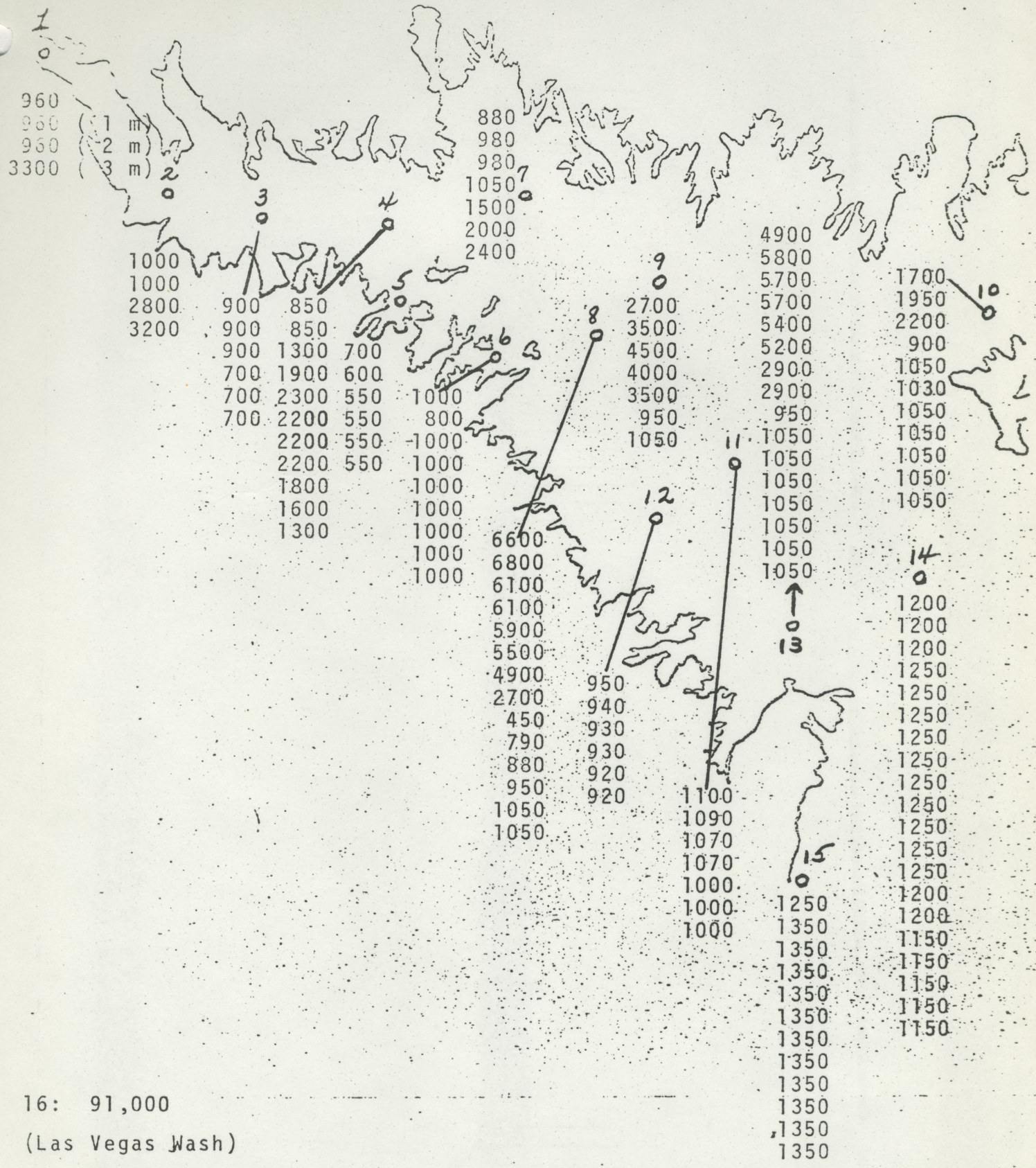
Table 7. Conductivity in Las Vegas Bay, 24 January, 1972.



Conductivity: µmho/cm

Depth: Surface to bottom at 5 m intervals. Deepest interval (bottom) less than 5 m at some stations.

Table 8. Conductivity in Las Vegas Bay, 31 January, 1972.



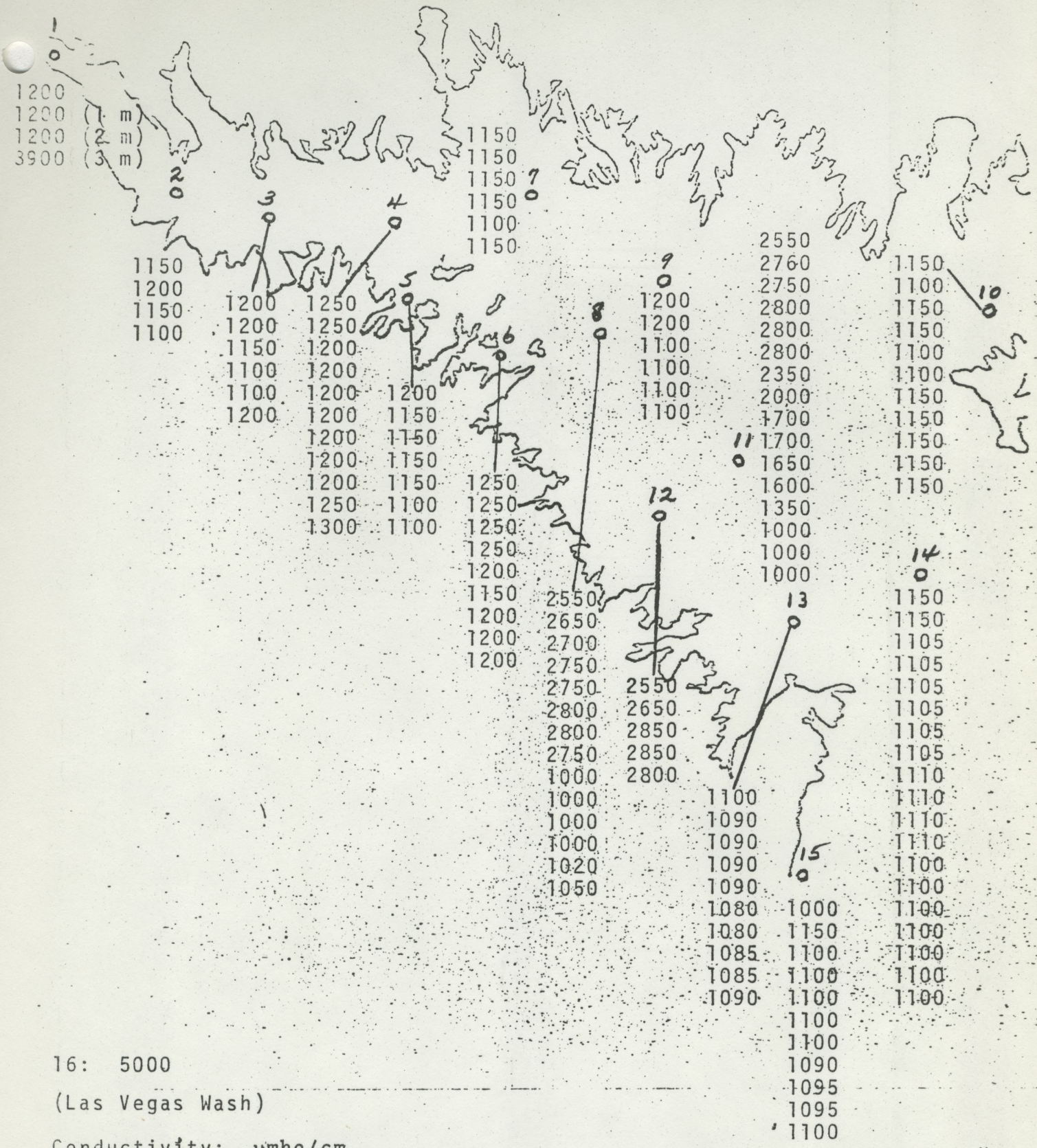
16: 91,000

(Las Vegas Wash)

Conductivity: µmho/cm

Depth: Surface to bottom at 5 m intervals. Deepest interval (bottom) less than 5 m in some cases.

Table 9. Conductivity in Las Vegas Bay, 7 February, 1972.



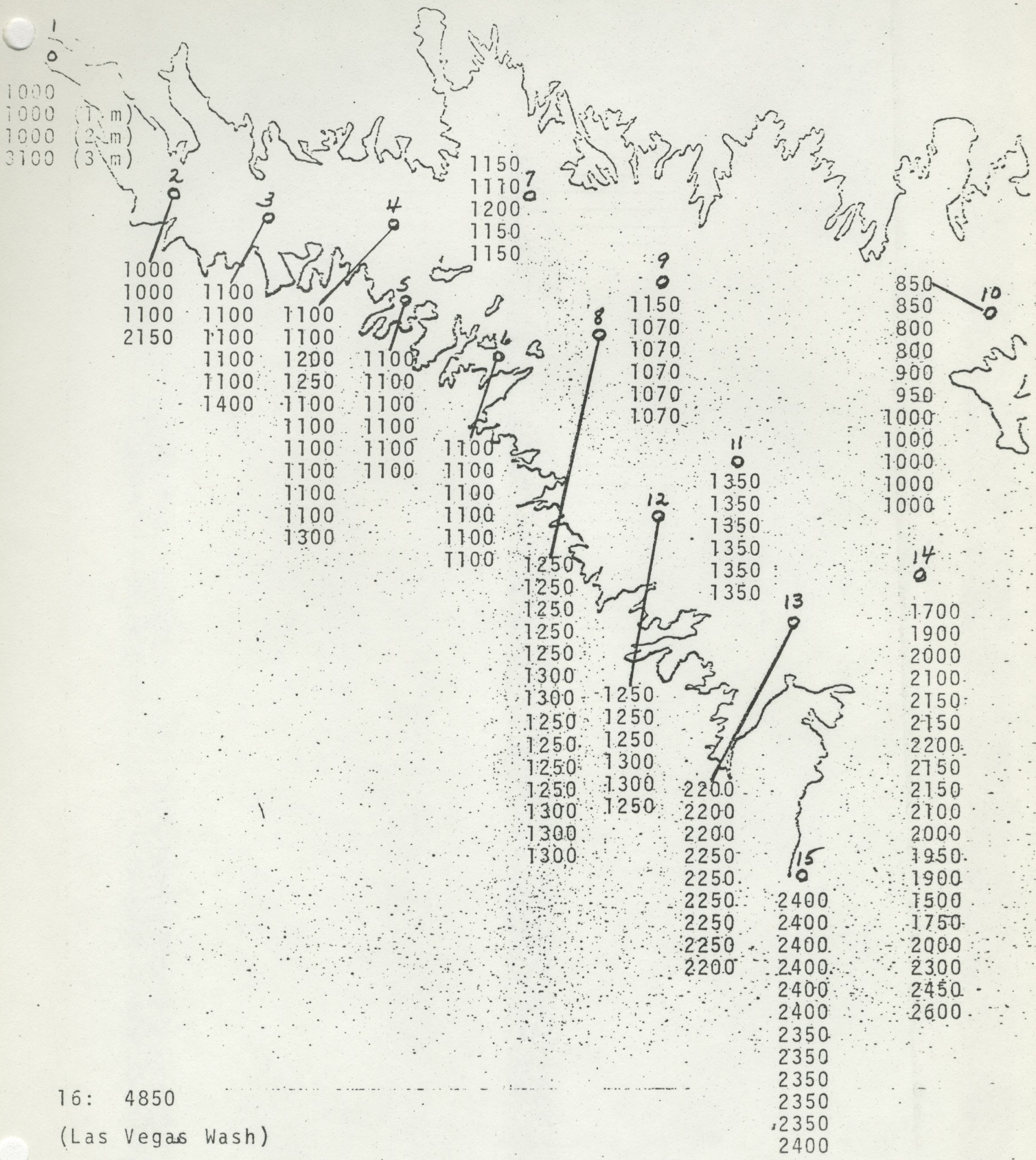
16: 5000

(Las Vegas Wash)

Conductivity: µmho/cm

Depth: Surface to bottom at 5 m intervals. Deepest interval (bottom) less than 5 m at some stations.

Table 10. Conductivity in Las Vegas Bay, 14 February, 1972.



16: 4850

(Las Vegas Wash)

Conductivity: µmho/cm

Depth: Surface to bottom at 5 m intervals. Deepest interval (bottom) less than 5 m at some stations.

conclusion is, of course, dependent on the assumption that observations made at one station are related to those adjacent to it.

On 17 January (Table 6), conductivities were higher than "average" at Station 10, with a maximum of 5200 at 10 meters. Data from adjacent stations indicate that a strongly tilted "cell" may have been present in the area containing Stations 10, 11, 13, 14 and perhaps 15. Dilution seems to have been occurring toward the bay entrance. Exceptionally low conductivity was recorded at depth at Stations 15, 14, and 13 on 17 January.

On 24 January no exceptionally high conductivity readings were obtained. The situation noted on 17 January had disappeared. Exceptionally low conductivity was noted at 40 m at Station 15, and at 70 m at Station 11.

A high conductivity "cell" apparently existed in the area sampled at Stations 8, 9, and 11 on 31 January, (Table 8), but disappeared by 7 February. Low conductivity was evident along the south shore of the bay at Stations 12, 5, and 3.

Data for conductivity above bottom at inner bay stations indicate that the "density currents" are intermittent during this period, and thus further substantiate evidence for mixing in this region.

The origin of conductivity discontinuities (whether from Boulder Basin or Las Vegas Wash), and their destination, are difficult to ascertain. The data suggest clockwise movement

of the water in the bay. In this case, bodies of water with higher salinity would probably owe their origin to the wash. This hypothesis is strengthened by data for January 31, Station 16, when exceptionally high conductivity (91,000) was detected and by results indicating establishment of thermal equilibrium by Station 3, but weakened by the lack of observation of high conductivity "cells" in the bay on 3, 7, and 14 February, and by high conductivity at depth, i.e. at Station 13, 10 January.

Confirmation should be sought by 1) continuous recording of wash conductivity to effect adequate surveillance for "slugs" of saline water, 2) establishment of the rate of movement of discontinuities in the bay, 3) analysis of the discontinuities for components in abnormally high concentration in the wash, such as phosphate, and 4) examination of the fate of water from Las Vegas Wash after it enters Las Vegas Bay by some suitable tracer technique.

The actual meaning of "conductivity" is important in evaluating the data. Conductivity data are dependent not only on the concentration but also on the kind of ions present under isothermal conditions. Thus, water of higher conductivity could be less dense than water of lower conductivity. However, at the values recorded, common ions would be at roughly hundredth molar concentrations at best, thus contributing very little to differences in density and constituting a minor barrier to mixing from an energy input standpoint.

Plankton

Plots of numbers of colonies or cells of the 6 most numerous genera are presented in Figs. 8-15. Table 30 lists the dates on which various genera were noted at particular stations.

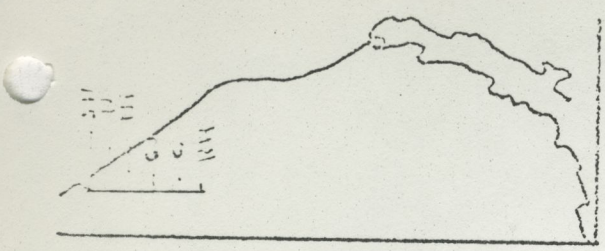
The scale used for plotting Figs. 8-15 is 10 counted units per millimeter of vertical scale, so that, although counts appear large, they were usually rather low, and reflect oligotrophic conditions for the most part. Colonies are indicated by wide bars, cells by narrow bars.

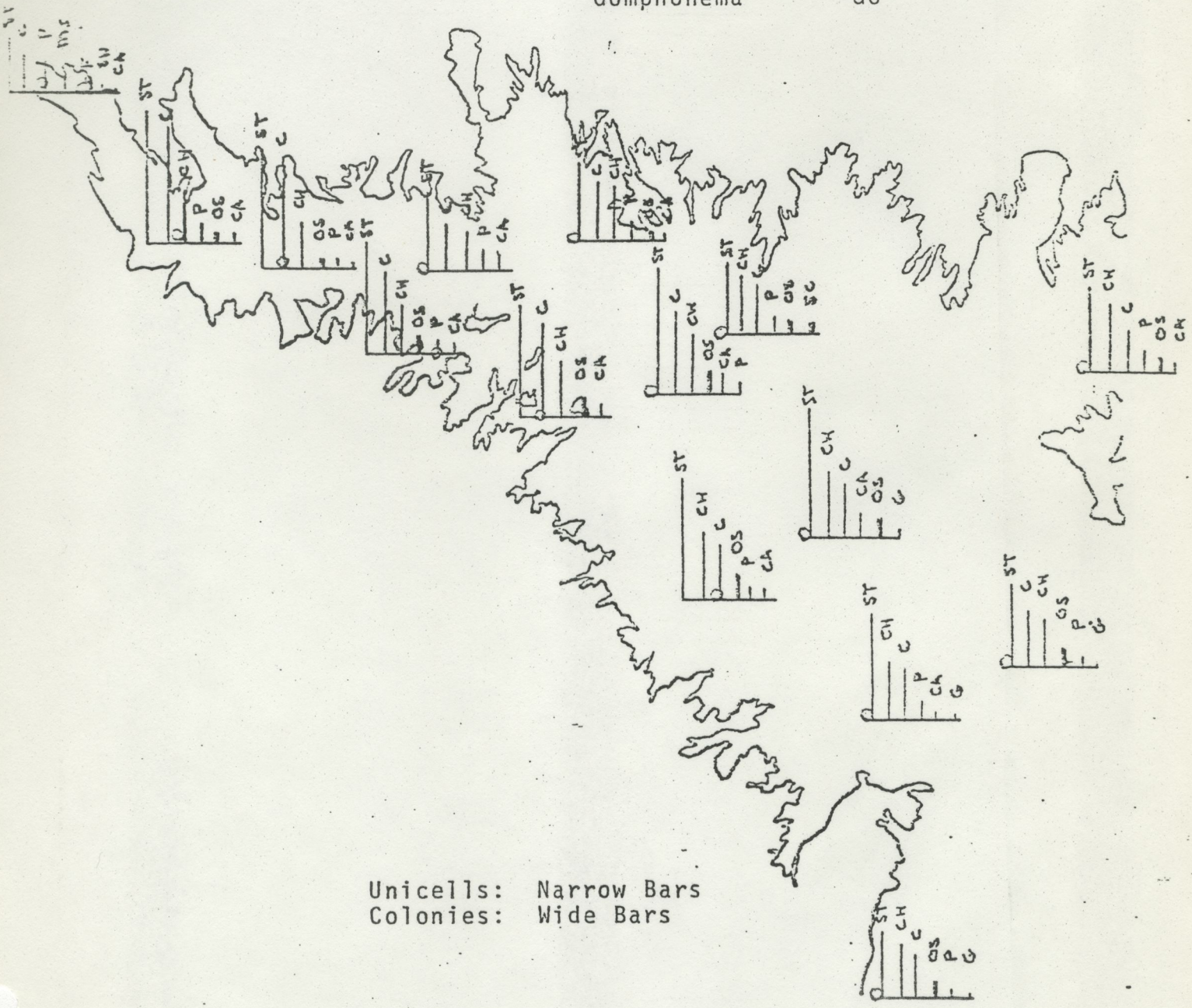
In January, numbers and kinds of phytoplankton were relatively uniform throughout the bay except for Station 1 where counts were lower. Stephanodiscus, Cyclotella (Diatoms), and Chlamydomonas (small, motile green alga) were not numerous throughout January. On 24 January, populations, especially of Stephanodiscus, had increased in the middle and outer bay (Stations 5-14) and at Station 15 in the main body of the lake near the intake tower. Populations decreased by 31 January, when most of the Stephanodiscus and Cyclotella were dead.

Micrasterius and Anabaena were apparently survivors from a previous period, and disappeared in January from the middle and outer bay. Others, such as Cymbella, Synedra, and Carteria are continuously present during the year. Oocystis had a predilection for the outer bay, especially Station 10.

Populations reached a minimum level on 3 February at which time Stations 1, 2, and 5 maintained higher populations than

Stephanodiscus	ST
Cyclotella	C
Chlamydomonas	CH
Peridinium	P
Oscillatoria	OS
Carteria	CA
Mallomonas	MS
Synedra	SN
Glenodinium	G
Scenedesmus	SC
Navicula	N
Nitzschia	Ni
Rhopalodia	RH
Gomphonema	Go





Unicells: Narrow Bars
Colonies: Wide Bars

Scale: 1 mm = 10

Fig. 8. Plankton in Las Vegas Bay 1/17/72

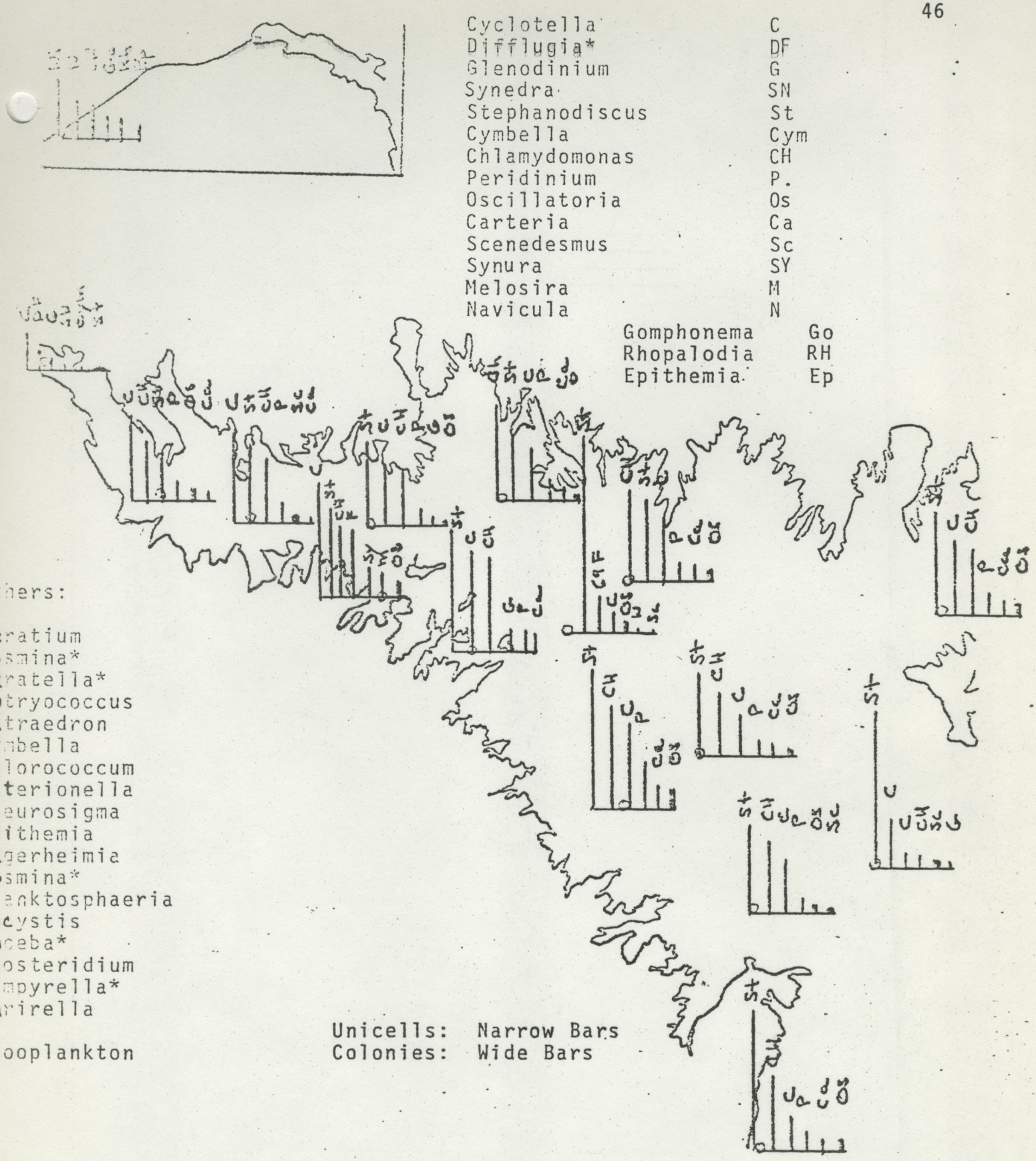


Fig. 9. Plankton in Las Vegas Bay 1/24/72

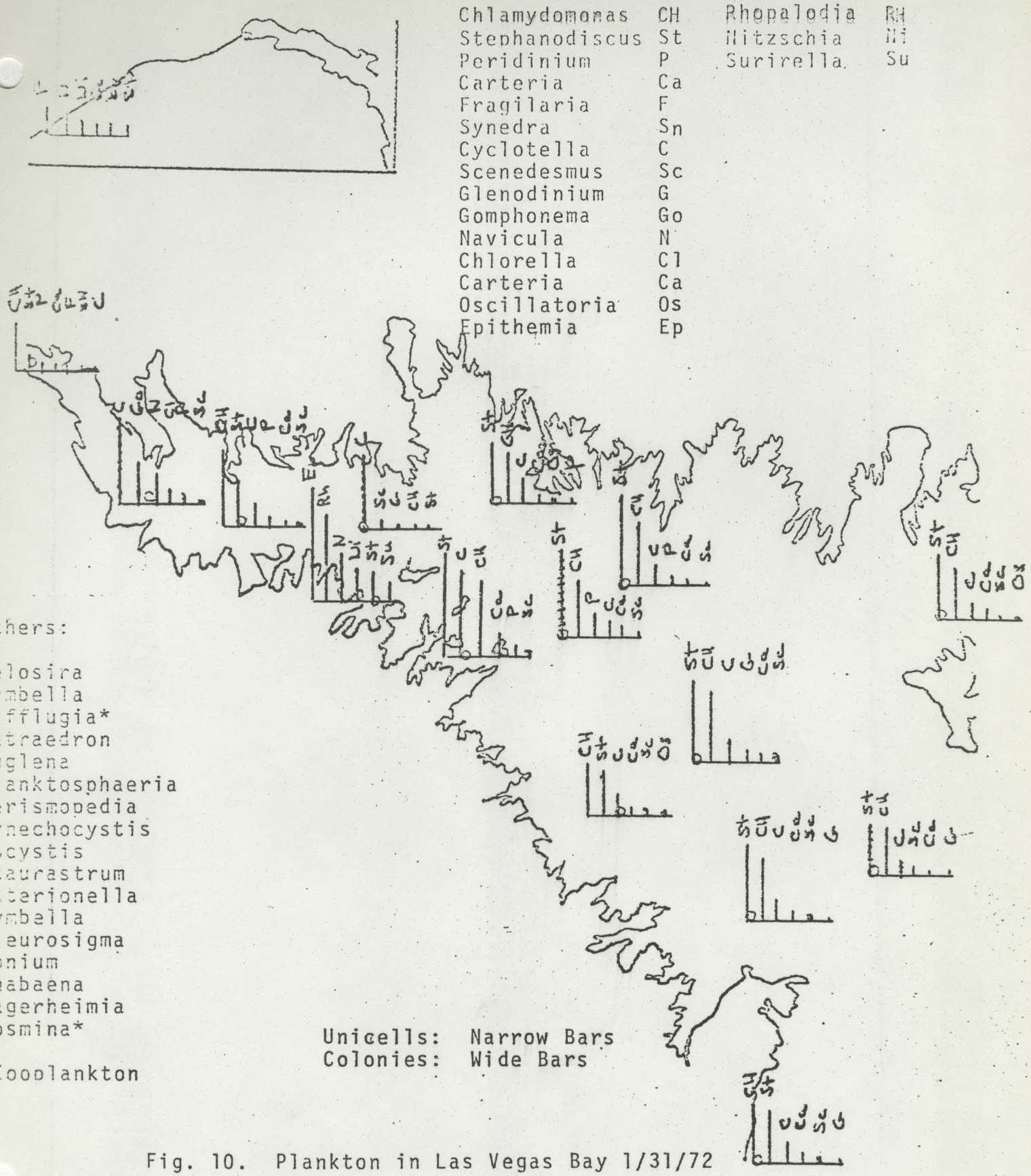


Fig. 10. Plankton in Las Vegas Bay 1/31/72

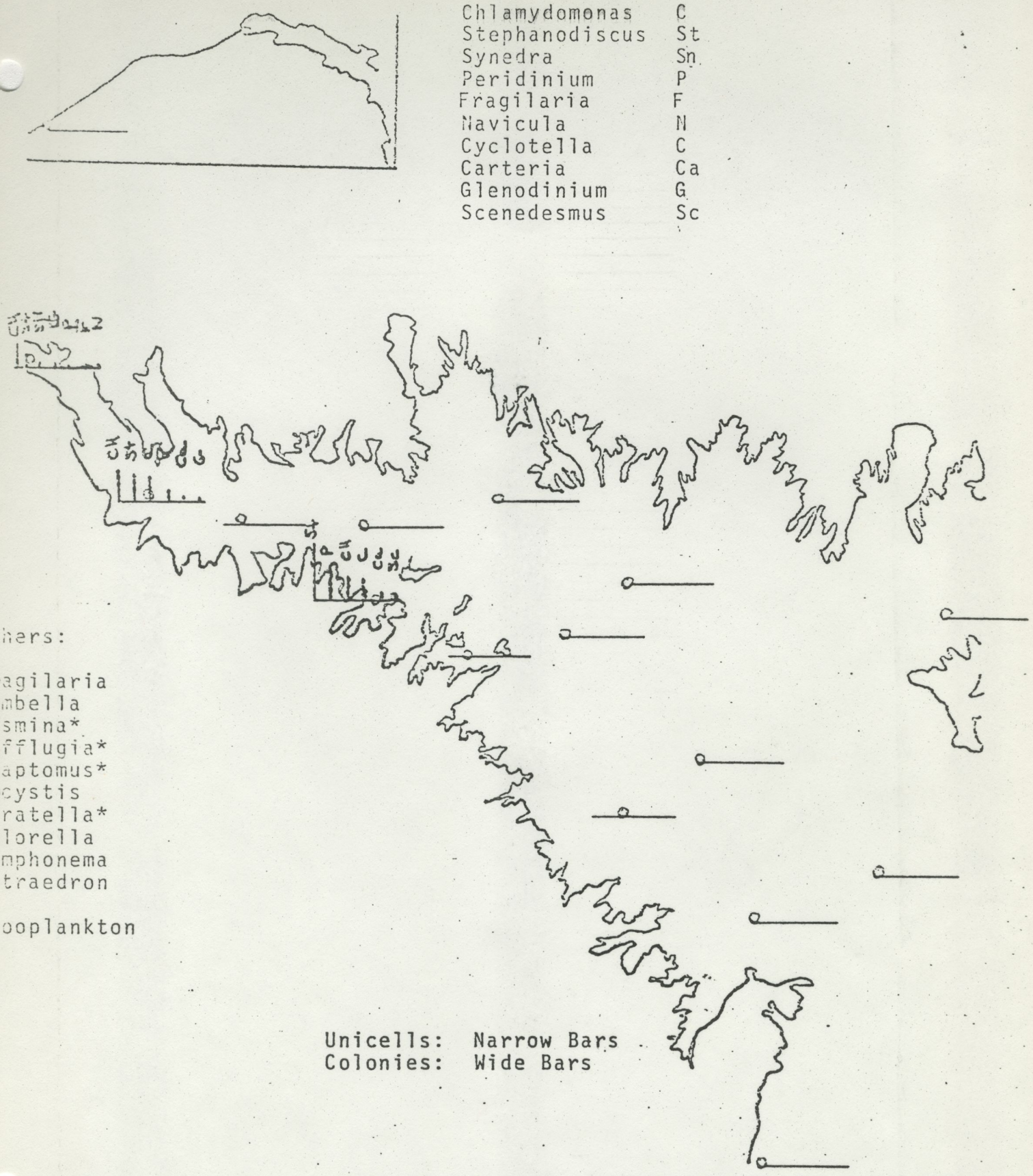
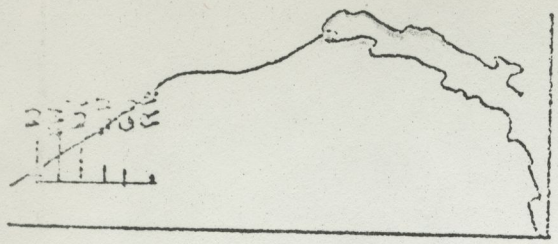


Fig. 11. Plankton in Las Vegas Bay, 2/3/72



Chlamydomonas	CH	Fragilaria	F
Peridinium	P	Nitzschia	Ni
Glenodinium	G	Gomphonema	Go
Synedra	Sn	Rhopalodia	R
Carteria	Ca		
Stephanodiscus	St		
Scenedesmus	Sc		
Cyclotella	C		
Oscillatoria	Os		

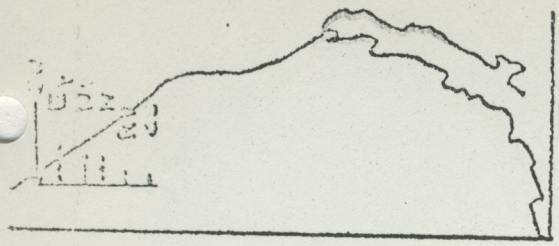
Others:

Difflugia*
Melosira
Diaptomus*
Cymbella
Chlorella
Epithemia**
Tetraedron
Lagerheimia
Oocystis
Planktosphaeria
Merismopedia
Amphiprore†
enatella*
Navicula
Cymbella

*Zooplankton
**Las Vegas Wash Only

Unicells: Narrow Bars
Colonies: Wide Bars

Fig. 12. Plankton in Las Vegas Bay 2/7/72



Chlamydomonas	CH	Oscillatoria	Os
		Stephanodiscus	St
Glenodinium	G	Fragilaria	F
Synedra	Sn	Platymonas	P
Carteria	Ca	Nitzschia	Ni
Cyclotella	C	Epithemia	Ep
Cymbella	Cym	Rhopalodia	RH
Scenedesmus	Sc	Cocconeis	CC
Peridinium	P		
Navicula	N		
Chlorella	Cl		

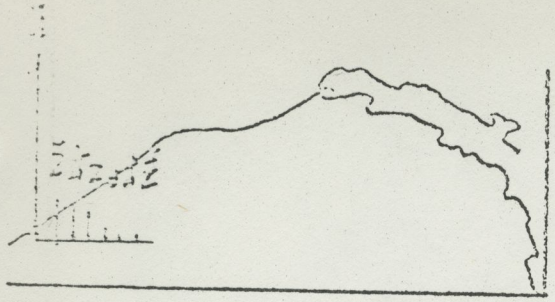
Others:

Gomphonema
Melosira
Cephalodella*
Bosmina*
Tetredron
Diaptomus*
Planktosphaeria
Pandorina
Pleurosigma+
Euglena+
Amphiprora+

*Zooplankton
+Las Vegas Wash only

Unicells: Narrow Bars
Colonies: Wide Bars

Fig. 13. Plankton in Las Vegas Bay, 2/14/72



Chlamydomonas	CH	Cymbella	Cym
Fragilaria	F	Scenedesmus	Sc
Glenodinium	G	Peridinium	P
Synedra	Sn	Navicula	N
Carteria	Ca	Oscillatoria	Os
Melosira	M	Stephanodiscus	St
Cyclotella	C		
		Nitzschia	Ni
		Epithemia	Ep
		Rhopalodia	R

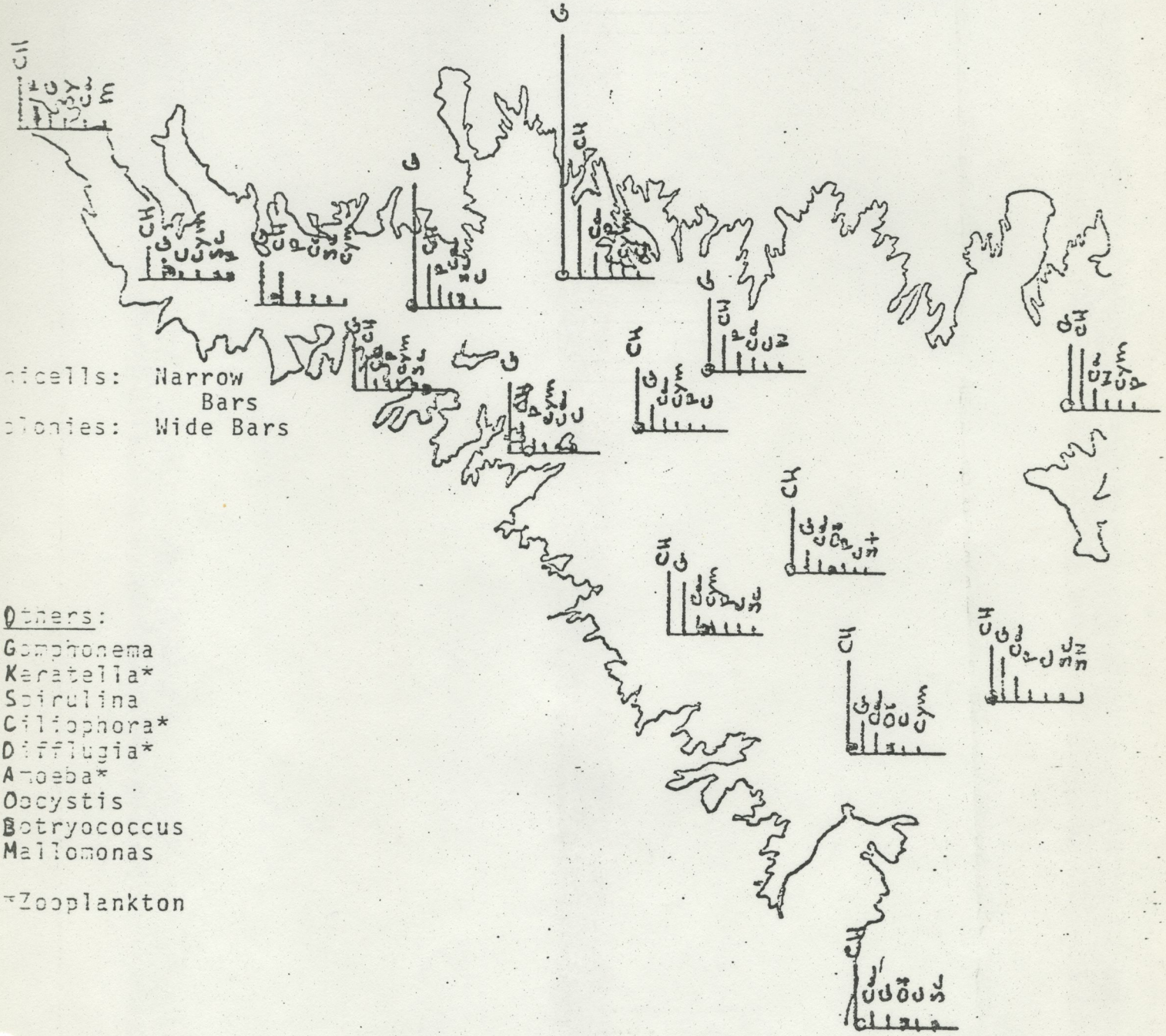
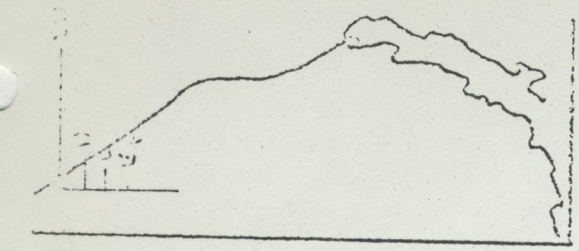
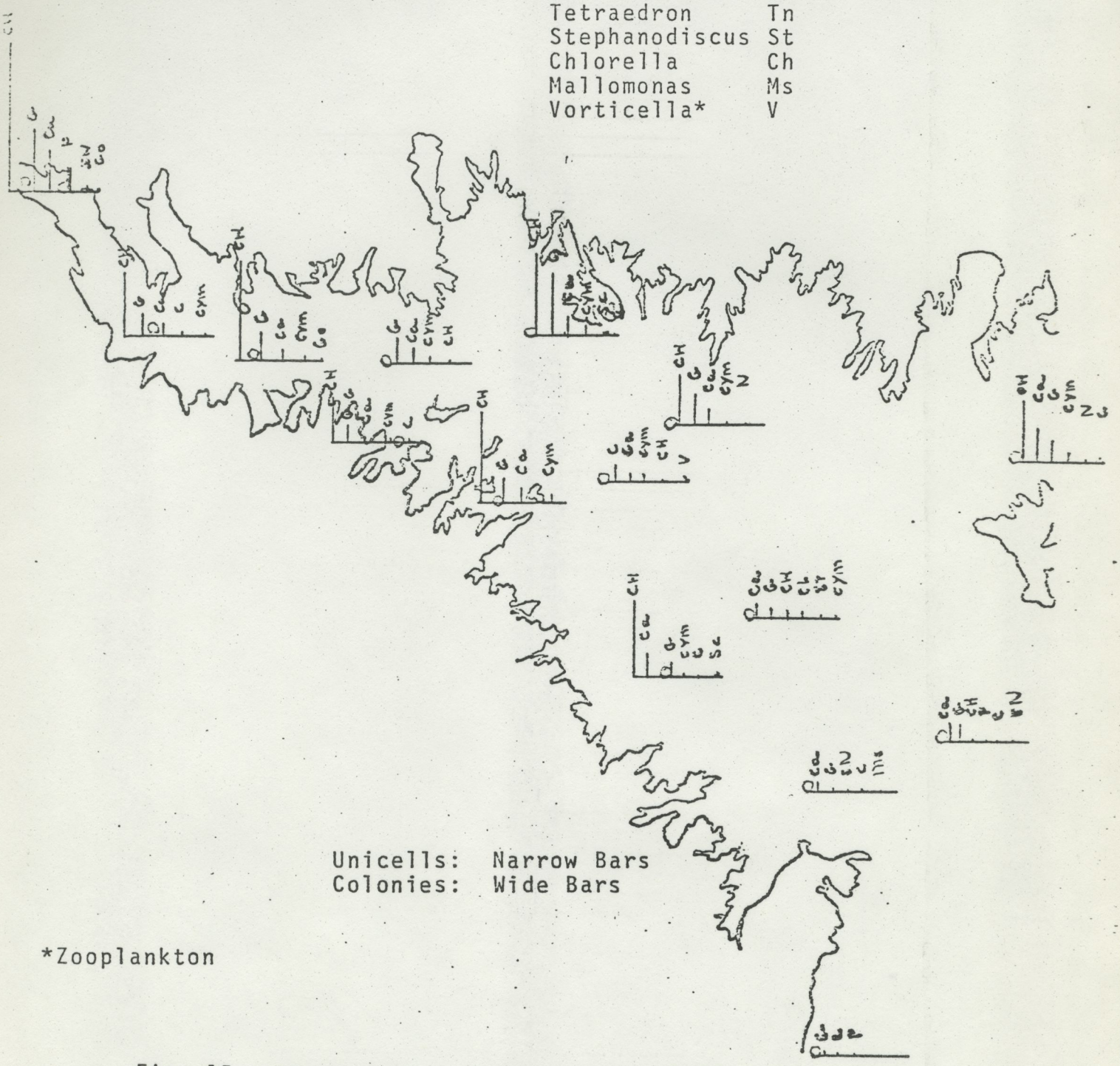


Fig. 14. Plankton in Las Vegas Bay, 2/22/72

Chlamydomonas	CH
Glenodinium	G
Carteria	Ca
Fragilaria	F
Synedra	SN
Gomphonoma	Go
Cyclotella	C
Cymbella	Cym
Scenedesmus	Sc
Tetraedron	Tn
Stephanodiscus	St
Chlorella	Ch
Mallomonas	Ms
Vorticella*	V





Unicells: Narrow Bars
Colonies: Wide Bars

*Zooplankton

Fig. 15. Plankton In Las Vegas Bay 2/28/72

elsewhere in the bay. Significant recovery was not evident until 22 February when again populations in the middle and outer bay were generally higher than at Stations 1, 2, and 3 where in addition most algae were dead. At Stations 4 and 7 in the middle bay Glenodinium (Dinoflagellate) had increased significantly. Chlamydomonas was the second most numerous at these stations, and more numerous than Glenodinium in all outer bay stations except Station 10.

On 28 February Glenodinium was largely dead at all stations. Numbers of the other phytoplankton remained low or decreased except for Chlamydomonas, which increased at Stations 1, 2, 3, and 6, and Carteria, which was somewhat more numerous at Station 10.

It is tempting to assume that biological events in the bay were correlated with the appearance of the January conductivity "cells" and bay circulation. However, the February decline could have been due to other factors, such as a sudden increase in heavy metals to the toxic level.

Certain Diatoms are characteristic of the wash but not of the bay. Among these are Gomphonema, Nitzschia, and Rhopalodia. Their distribution in surface samples is indicated in Table 30. Gomphonema was frequently found at many locations during the period, but Nitzschia appeared only on 31 January and 7 February, and Rhopalodia on 31 January and 28 February. All three, plus Surirella and Pleurosigma, were found at the surface of Station 5 on 31 January. These genera provide some clues to the dispersal of water from Las Vegas Wash throughout the bay.

Spring Oligotrophy

This period is best discussed in terms of the density current hypothesis, which postulates that the colder waters of Las Vegas Wash form a density current flowing into the hypolimnion of the bay for most of the season, but that in late spring, as warming of the inflowing stream occurs, the current becomes unstable and mixes with the water of the inner bay, thus making nutrients available for phytoplankton growth.

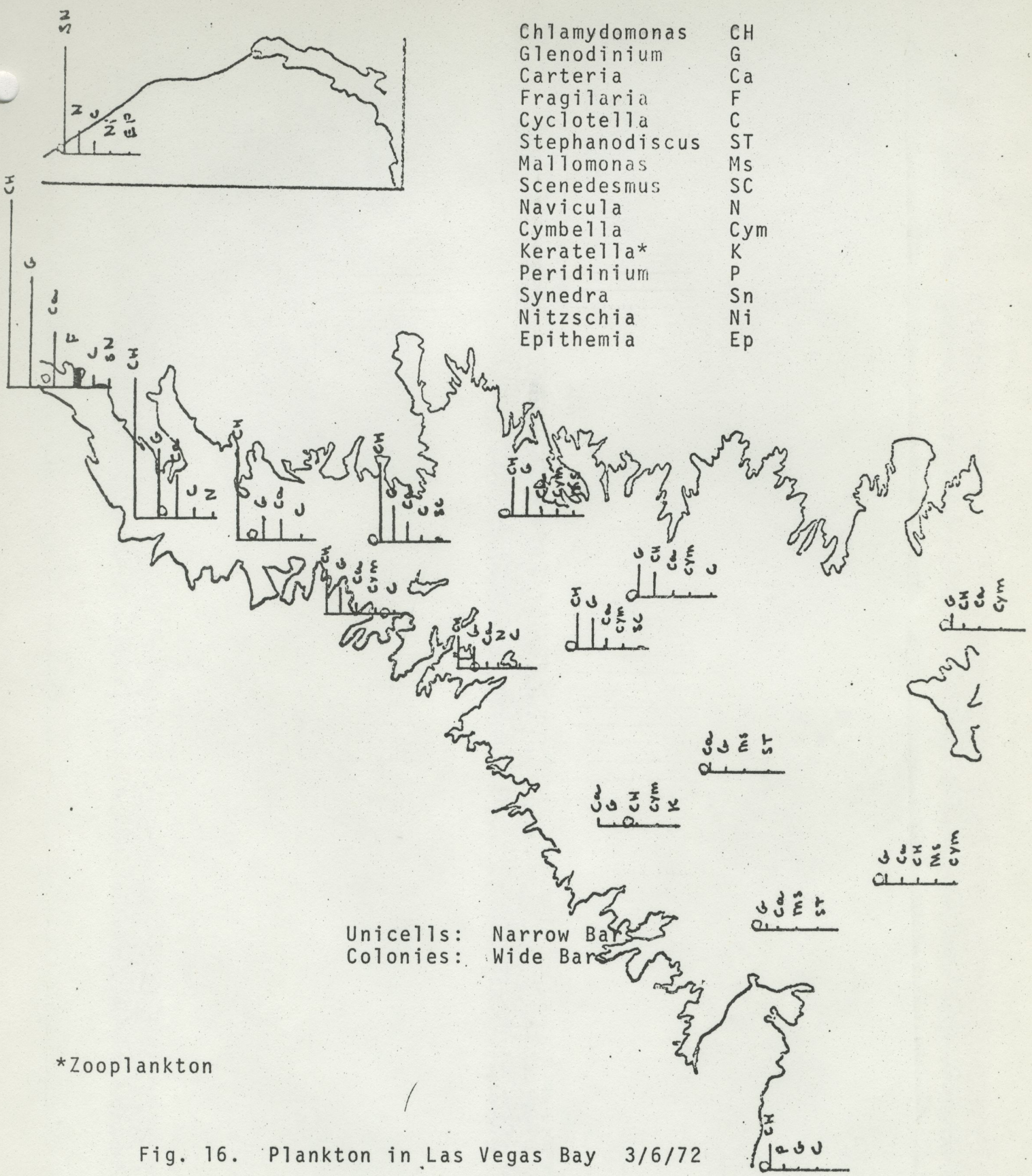
In the following discussion, phytoplankton data are presented first to show when and where oligotrophic conditions existed, and to illustrate the trend toward eutrophy developing in the inner bay in April and May. Then, results of determinations of temperature, oxygen, and conductivity are examined for clues to the behavior of the phytoplankton.

Plankton

Figs. 16 through 28 are plots of the six most numerous genera occurring at each station on each sampling date throughout the period under discussion. Less numerous forms are indicated in Table 30.

Throughout March, low numbers were observed in the bay. Algae were relatively more numerous at Stations 1, 2, 3, and 4 on 6 March; Stations 1 and 15 on 13 March (*Carteria* dominant) and Station 1 on 20 March, where *Carteria* persisted. A catastrophic drop in the *Carteria* population had occurred on 28 March.

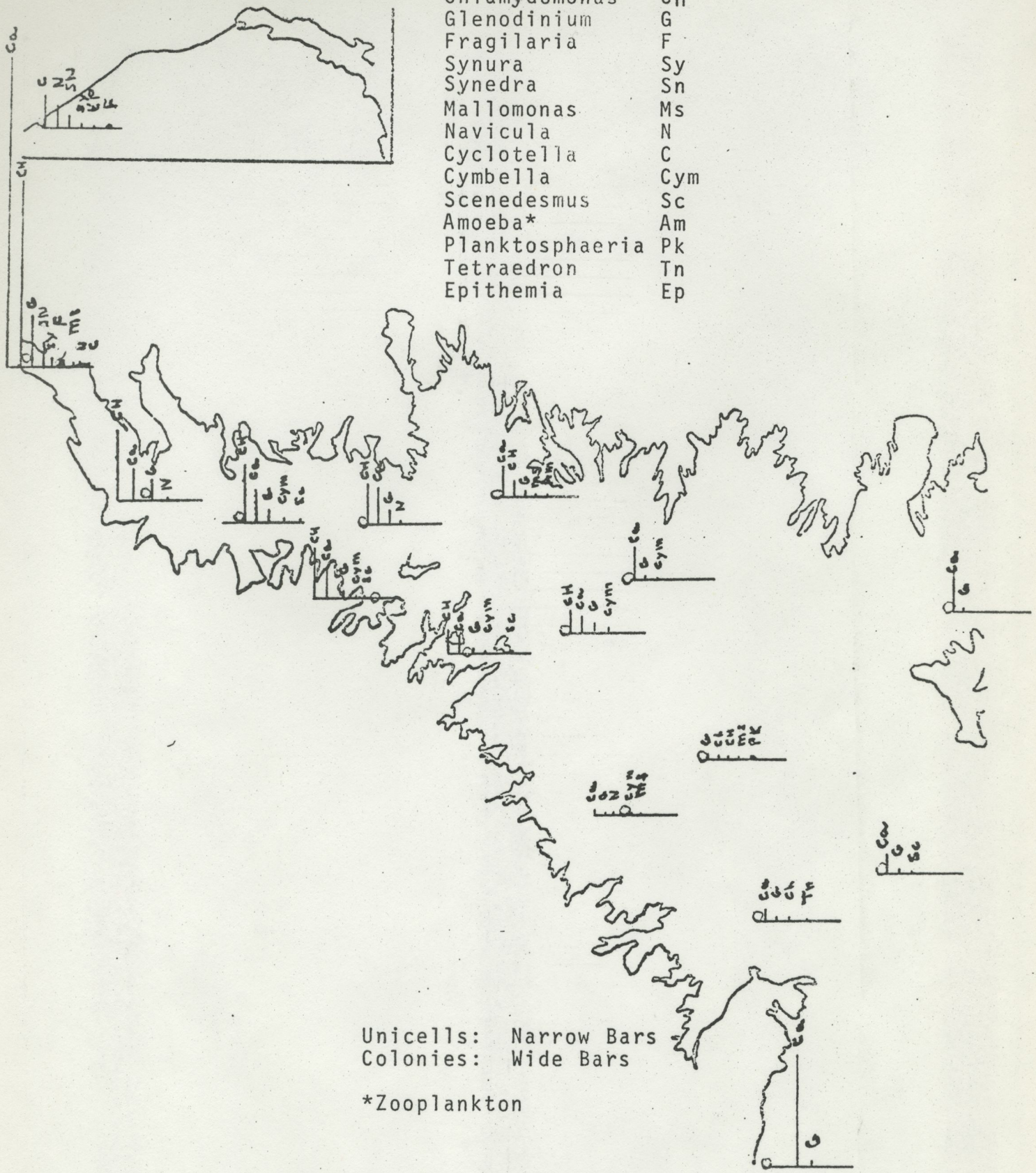
On 3 April *Hemidinium* reached significant numbers at Station 1. Numbers of phytoplankton at Station 2 were relatively



*Zooplankton

Fig. 16. Plankton in Las Vegas Bay 3/6/72

Carteria	Ca
Chlamydomonas	CH
Glenodinium	G
Fragilaria	F
Synura	Sy
Synedra	Sn
Mallomonas	Ms
Navicula	N
Cyclotella	C
Cymbella	Cym
Scenedesmus	Sc
Amoeba*	Am
Planktosphaeria	Pk
Tetraedron	Tn
Epithemia	Ep



Unicells: Narrow Bars
Colonies: Wide Bars

*Zooplankton

Fig. 17. Plankton in Las Vegas Bay 3/13/72

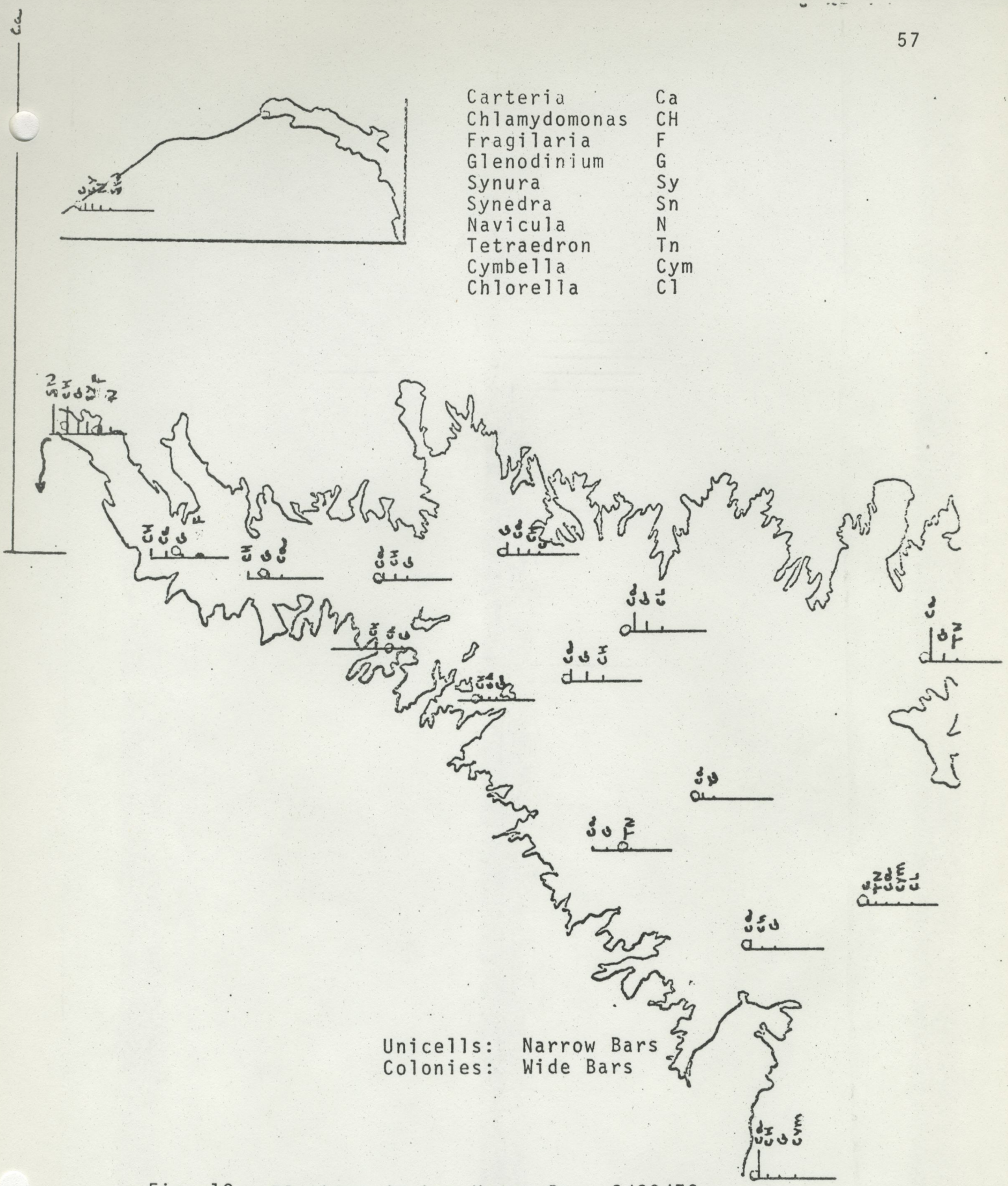


Fig. 18. Plankton in Las Vegas Bay 3/20/72

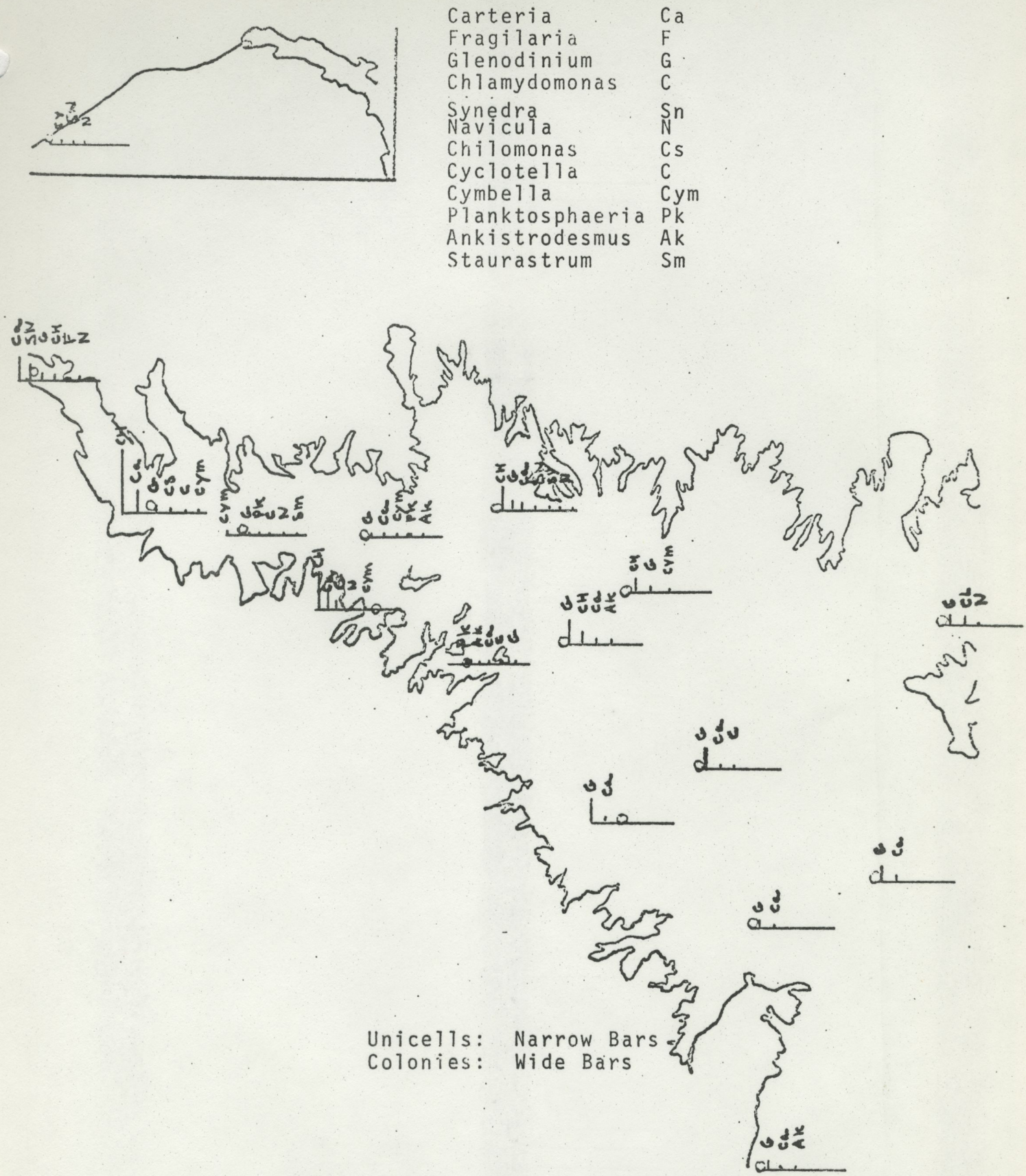


Fig. 19. Plankton in Las Vegas Bay 3/28/72

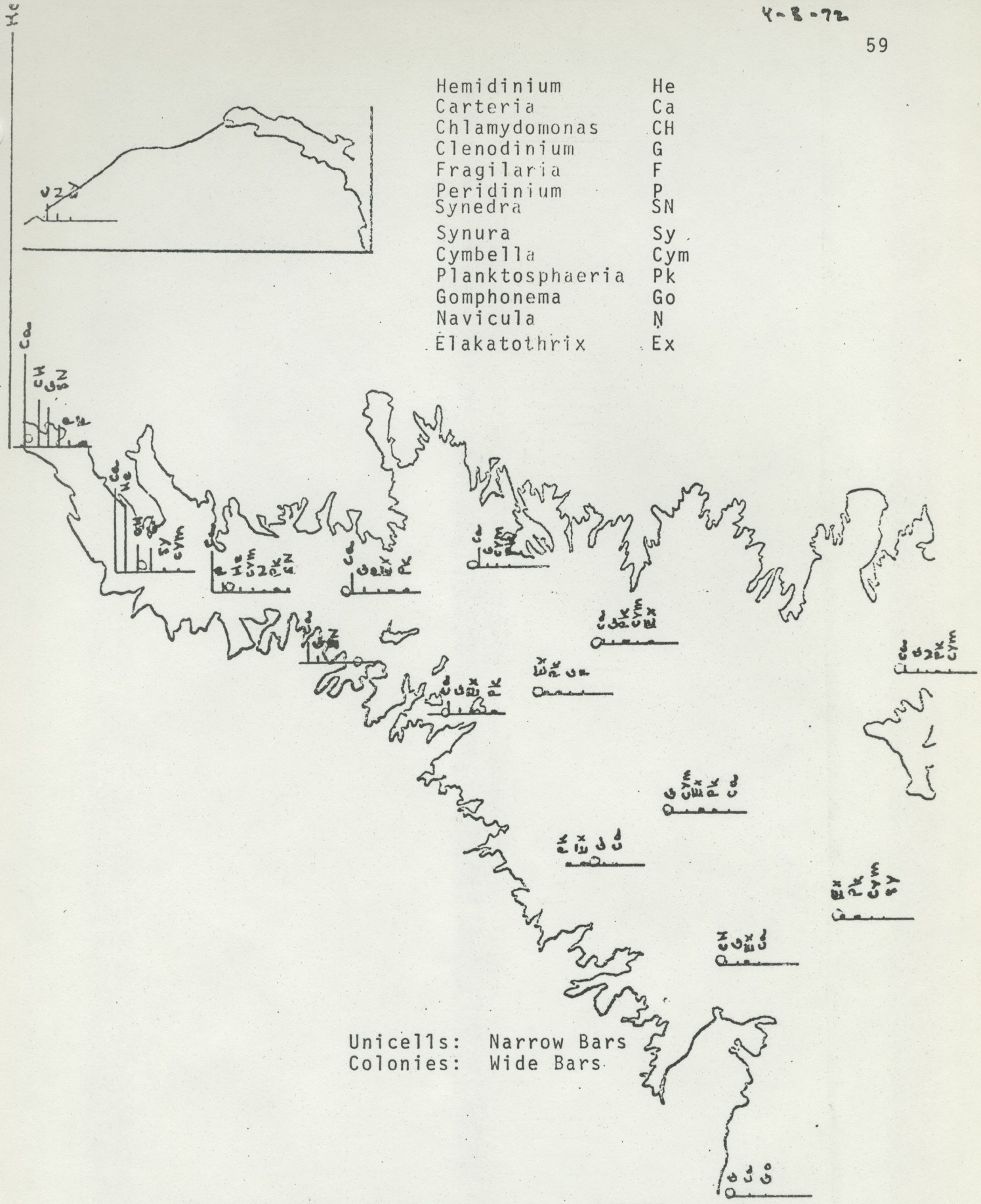


Fig. 20. Plankton in Las Vegas Bay 4/3/72

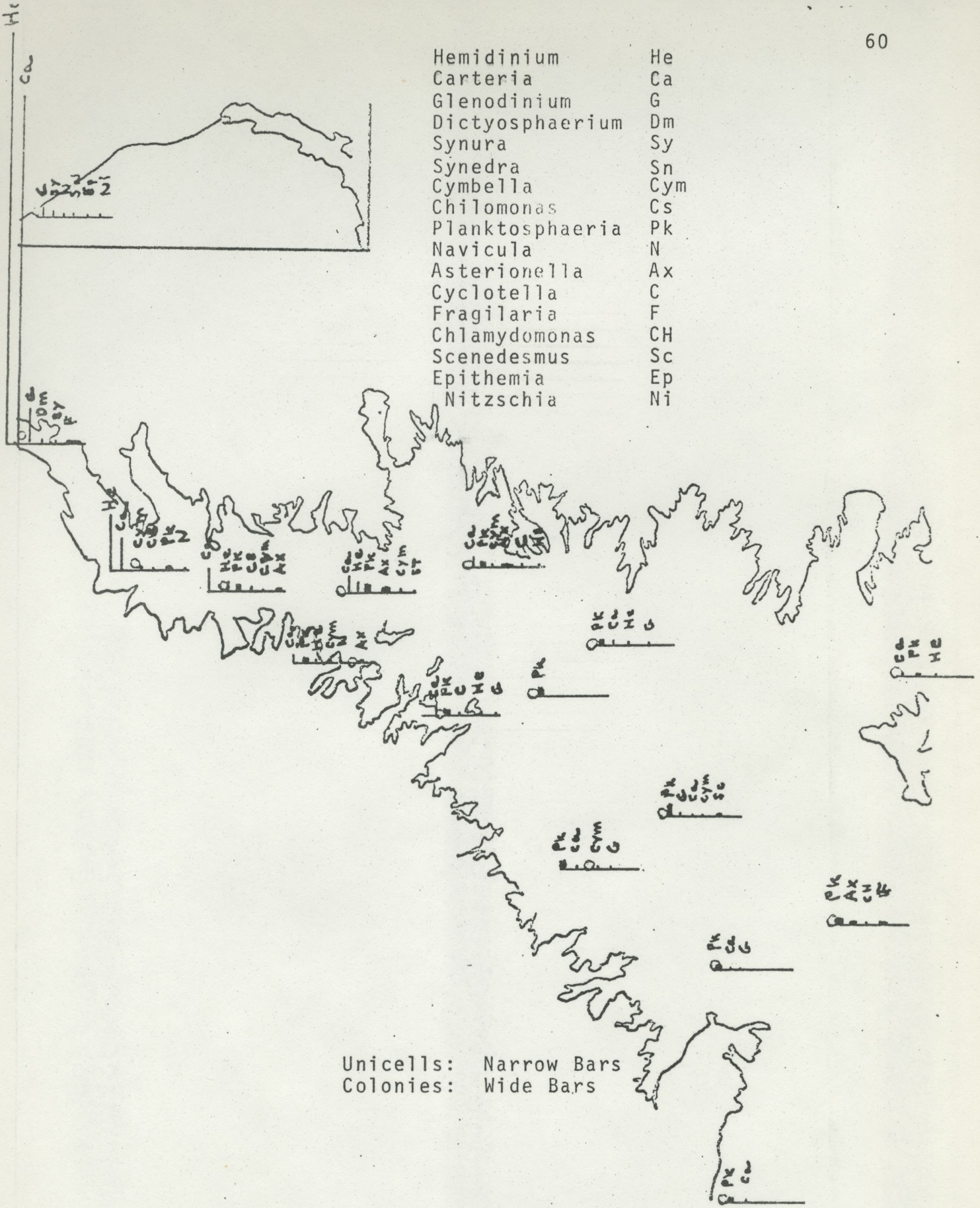
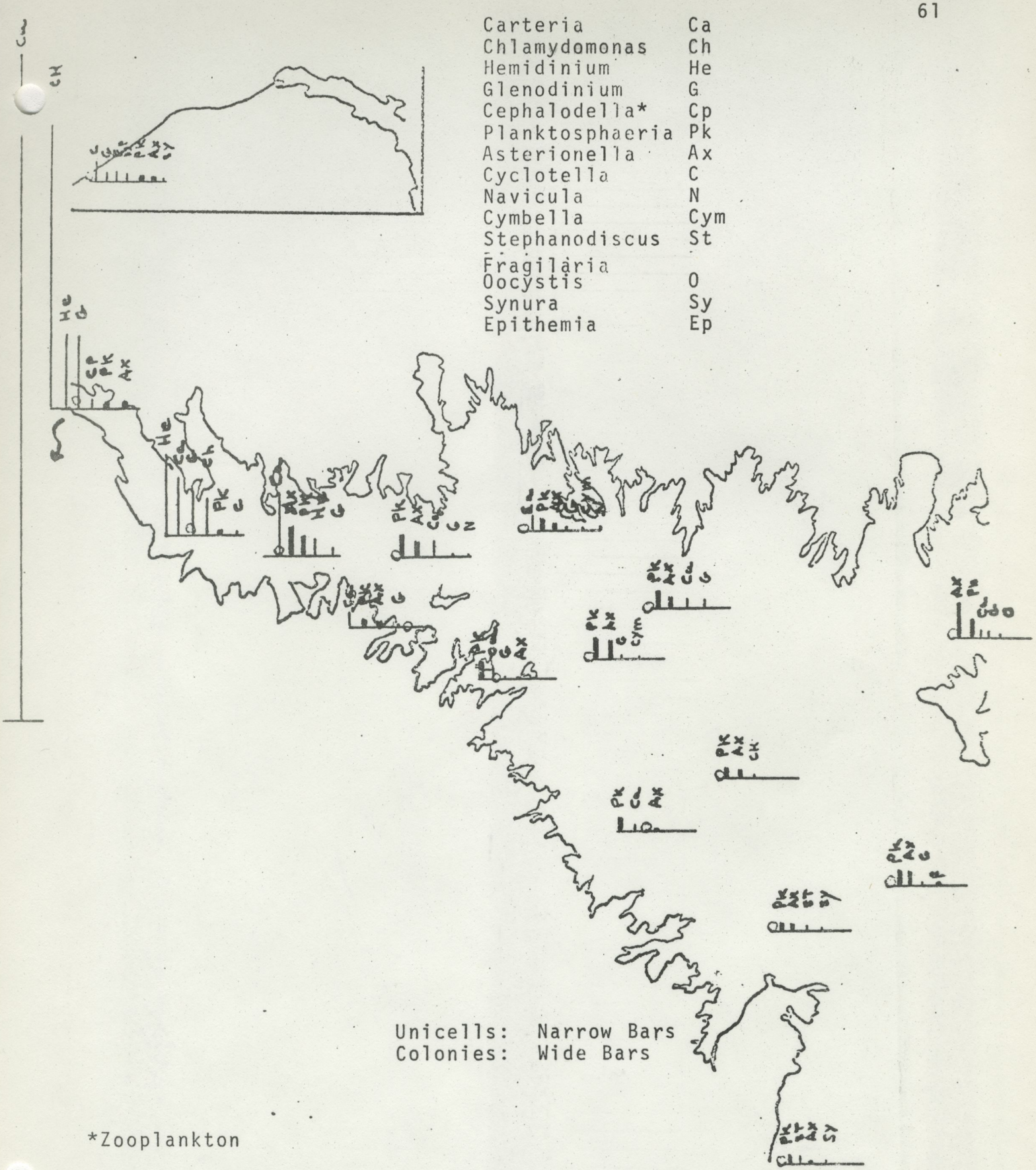


Fig. 21. Plankton in Las Vegas Bay 4/10/72



*Zooplankton

Fig. 22. Plankton in Las Vegas Bay 4/17/72

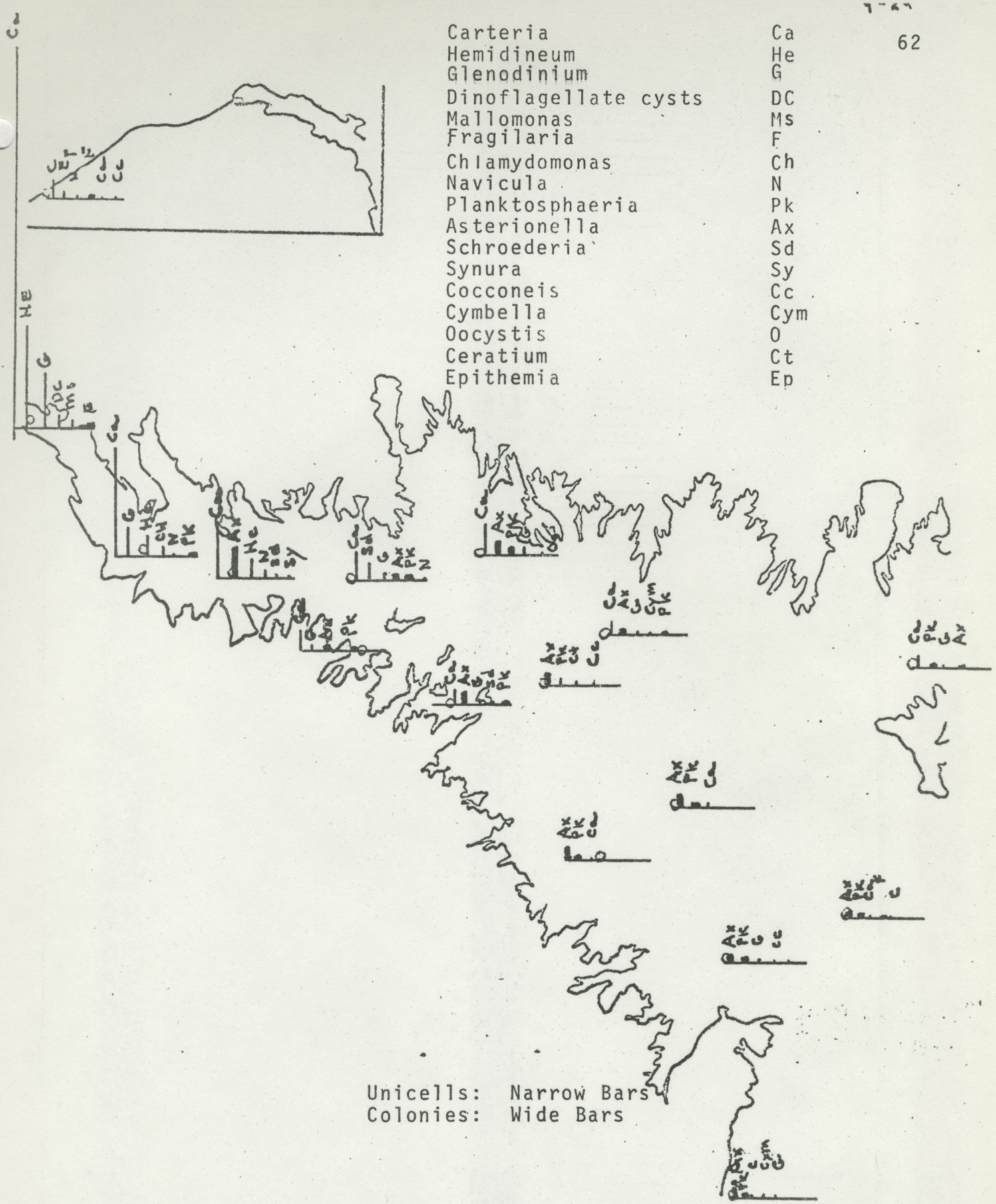
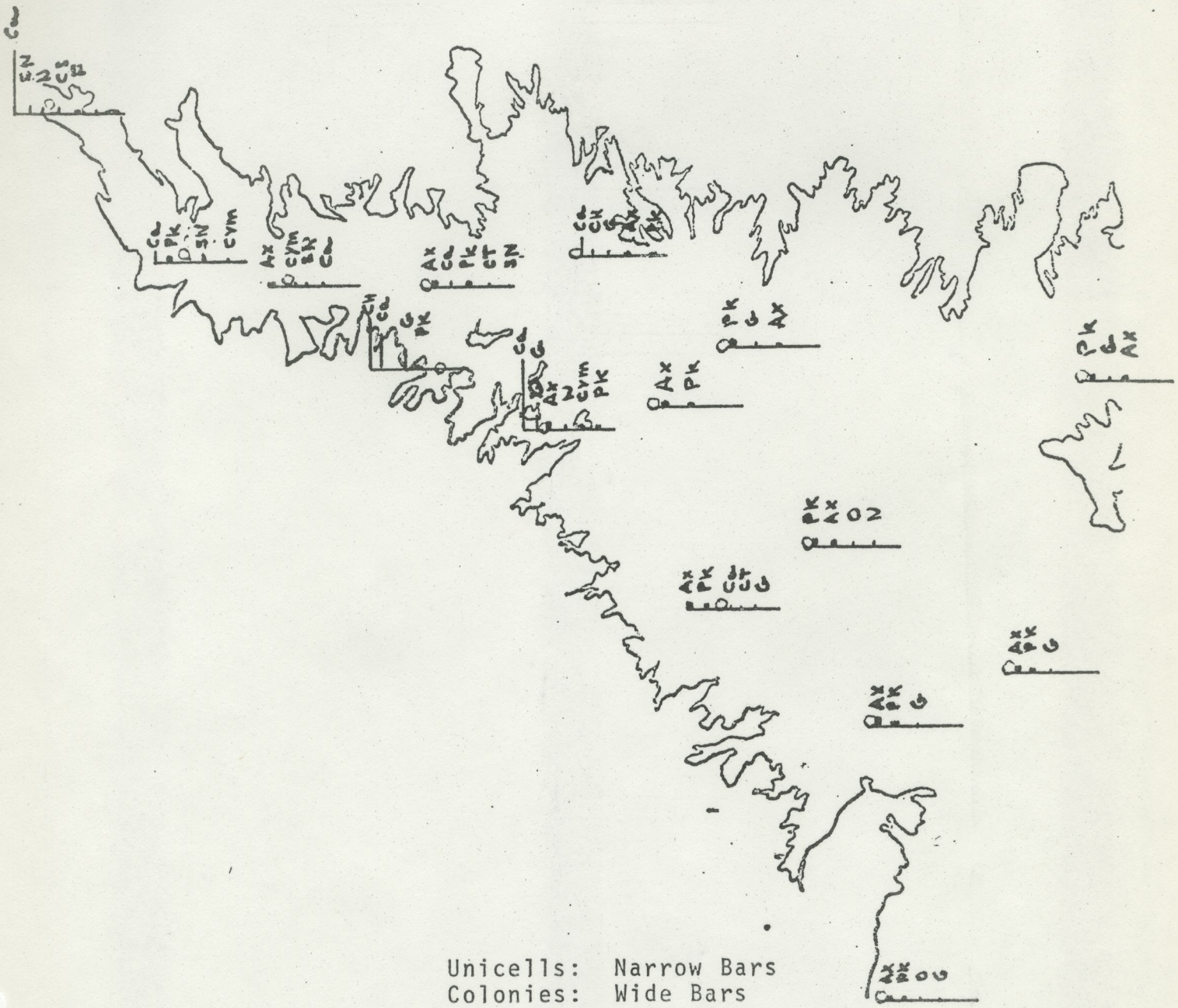


Fig. 23. Plankton in Las Vegas Bay 4/24/72

Carteria	Ca
Fragilaria	F
Navicula	N
Chilomonas	Cs
Planktosphaeria	Pk
Asterionella	Ax
Synedra	Sn
Cymbella	Cym
Ceratium	Ct
Glenodinium	G
Oocystis	O
Chlamydomonas	Ch



Unicells: Narrow Bars
Colonies: Wide Bars

Fig. 24. Plankton in Las Vegas Bay 5/1/72

Carteria	Ca
Chlamydomonas	Ch
Fragilaria	F
Planktosphaeria	Pk
Cyclotella	C
Glenodinium	G
Asterionella	As
Synedra	Sh
Ceratium	Ct
Hemidinium	He
Oocystis	O
Oscillatoria	Os
Navicula	N
Platymonas	Py
Nitschia	Ni

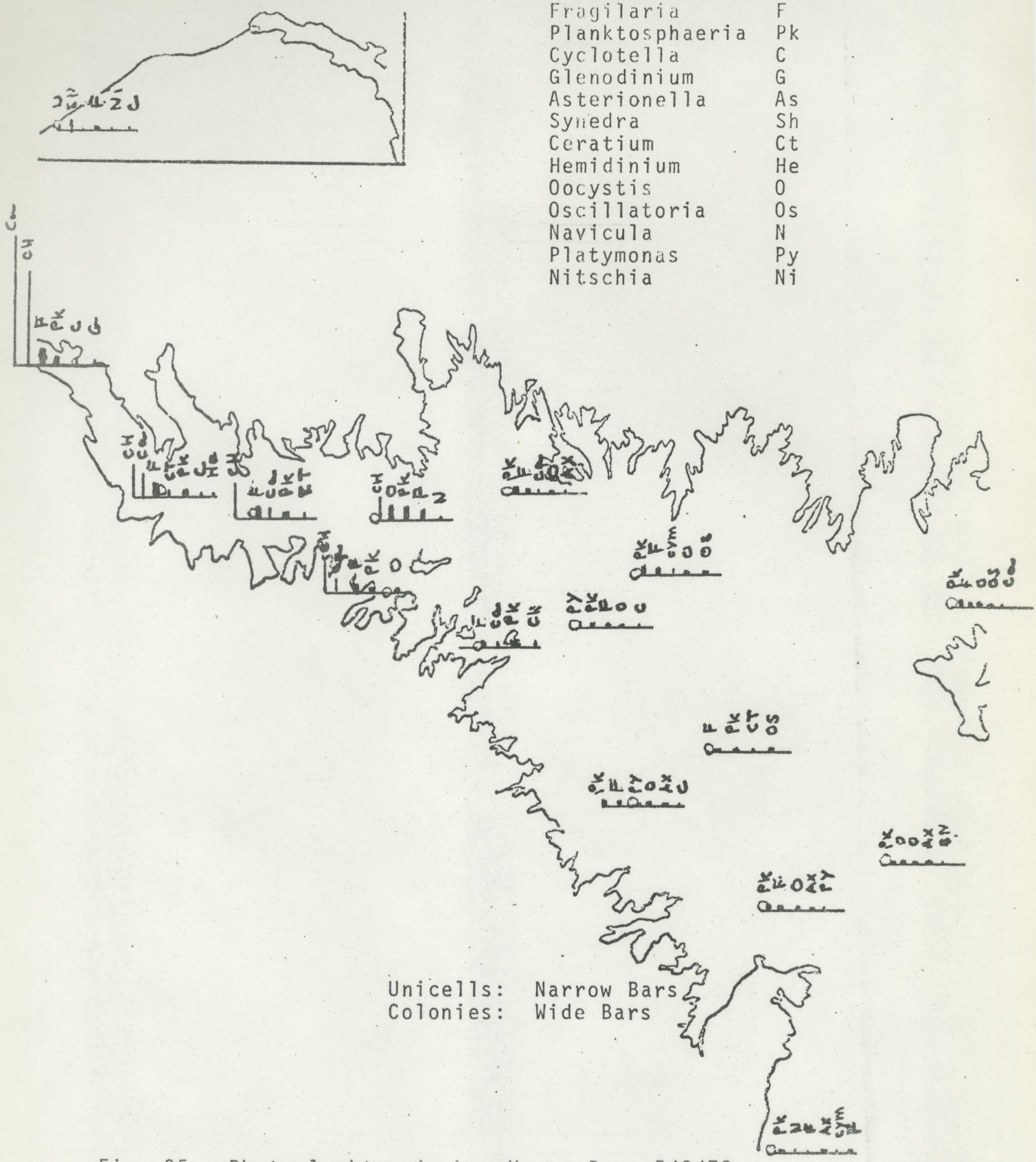


Fig. 25. Phytoplankton in Las Vegas Bay 5/8/72

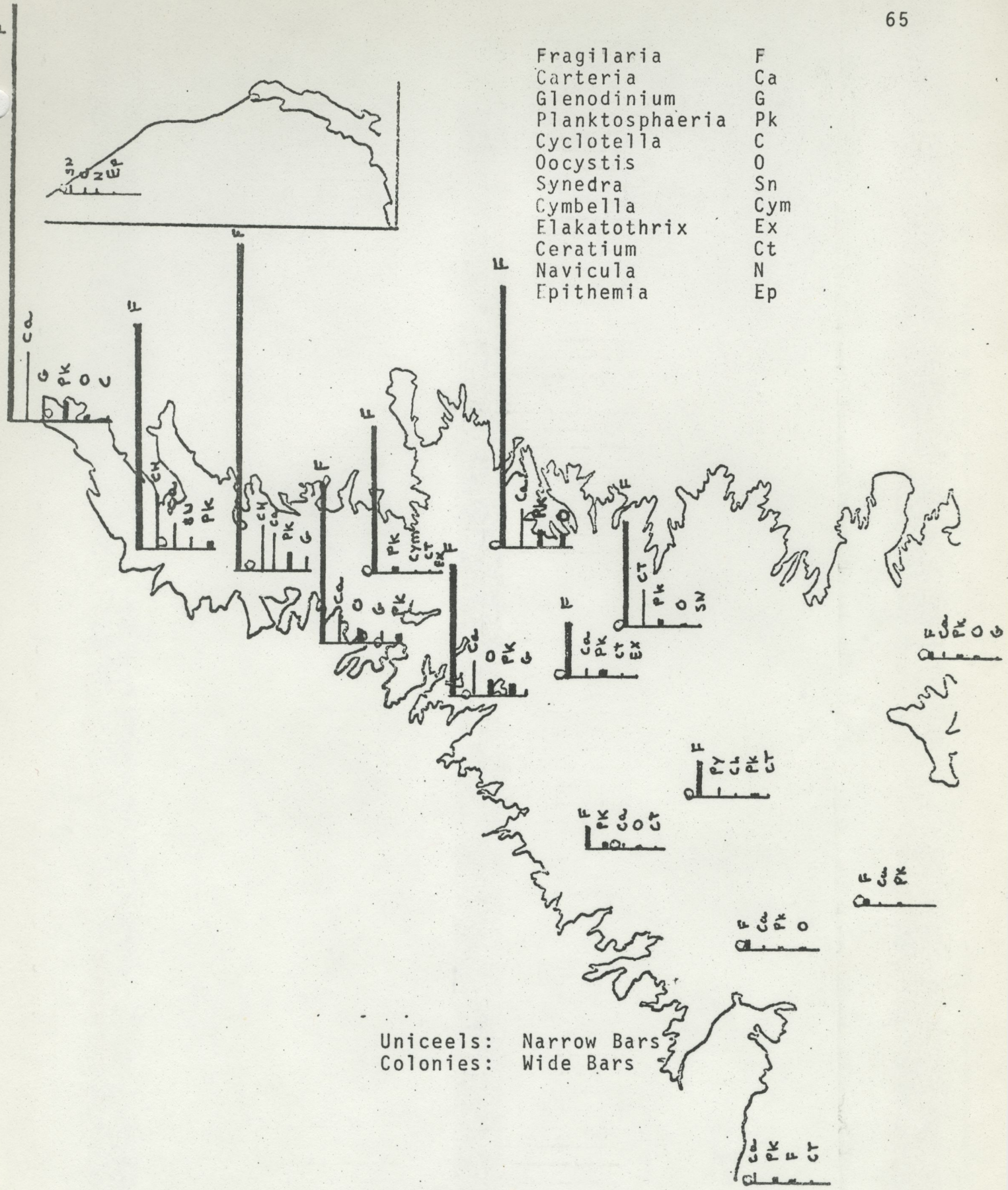


Fig. 26. Plankton in Las Vegas Bay 5/15/72

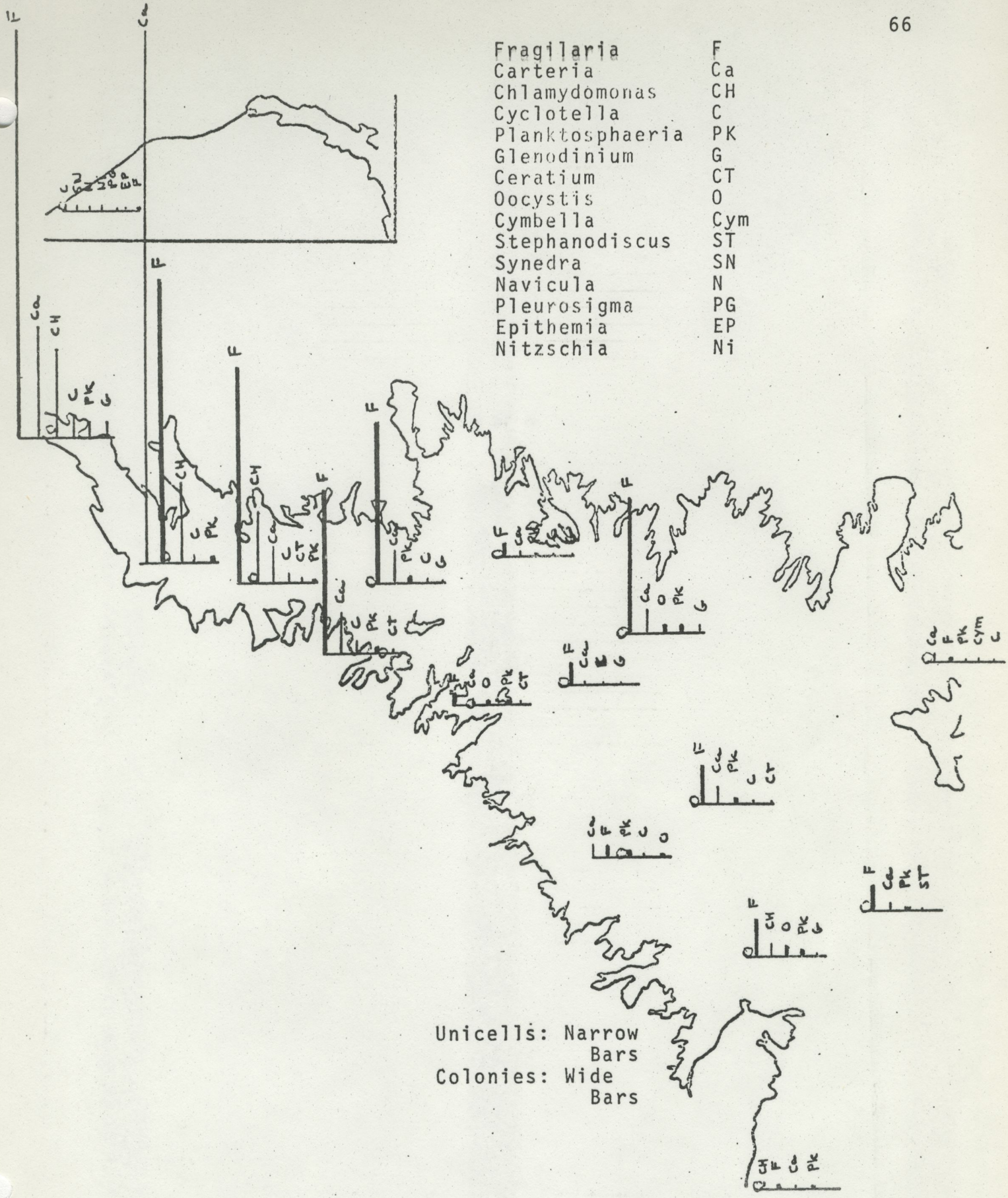


Fig. 27. Plankton in Las Vegas Bay 5/22/72

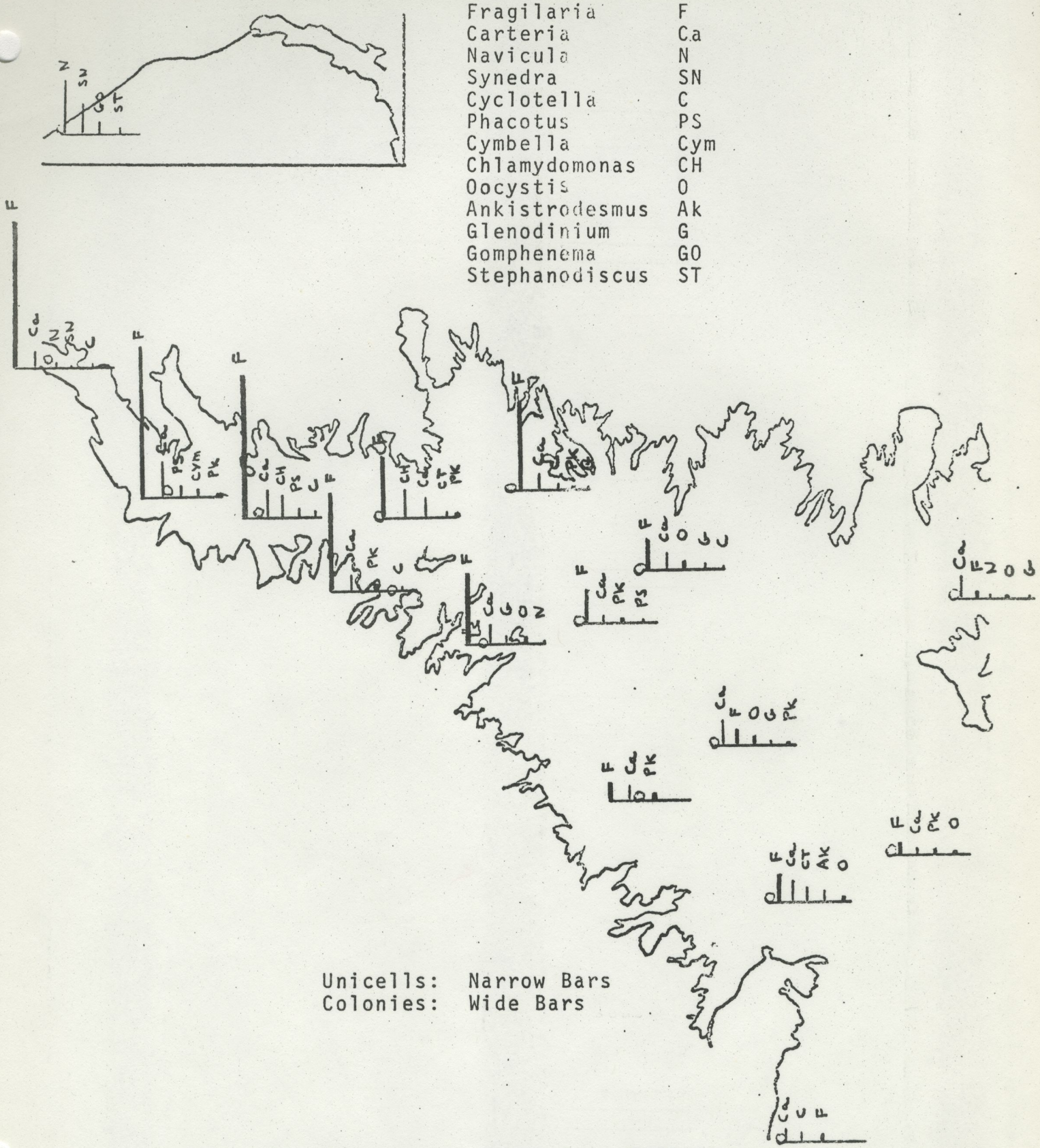


Fig. 28. Plankton in Las Vegas Bay 5/30/72

low and were very low at other stations. The Carteria population began significant recovery on 10 April at Station 1 and by 17 April it and Chlamydomonas were dominant and Hemidinium was low. The remainder of the bay, except for Station 2, continued to yield very low populations throughout April. At Stations 3 through 15, Asterionella, Planktosphaeria, and Carteria seemed dominant, but numbers were very low.

On 1 May, another precipitous decline had occurred at Station 1. Subsequently, a large increase in Fragilaria (colonial diatom) occurred with especially large numbers at Stations 1, 2, 3, 4, 5, 6, 7, and 9 on 15 May. With an average of 15 cells per colony, the more than 800 colonies per ml at Station 1 represented more than 12,000 cells per ml. Hutchinson considers 7,000 cells per ml as a "great Fragilaria population". On 15 May, Stations 10, 11, 12, 13, 14, and 15 recorded the usual very low numbers although Fragilaria was present.

The data for 22 May illustrate continued high populations of viable Fragilaria at Stations 1 through 5. With the exception of Station 9, relatively low numbers of Fragilaria were recorded for the remainder of the bay. The anomalously high incidence of Fragilaria at Station 9, low populations at Stations 6 and 7 in the middle bay, and the consistency of data for the outer bay possibly reflect the interaction of the effects of wind, currents, and the morphological complexity of the bottom of the bay, especially the Sand Island Reef.

The Fragilaria in the outer bay might possibly have been present as the result of seeding from inner bay stations rather than growth, although oxygen data indicate continued photosynthetic activity. By 30 May, the Fragilaria bloom had subsided and most of the remaining cells were dead.

Fragilaria was distributed primarily at the surface at Station 4 on May 30, as indicated by the data in Table 11. Numbers present elsewhere in the column of water suggest a "rain" of dead cells from the surface.

Large populations of Carteria and Glenodinium were noted at 30 meters. Accumulation of phytoplankton at a specific location associated with increased water density is a frequently encountered phenomenon, although the fact that motile forms occurred at depth under reduced illumination suggests that they may be utilizing heterotrophic nutrition and therefore acting in this instance more like animals than plants. Studies on diurnal phytoplankton migration might be profitable. Genera found 1 meter above the bottom were significantly different than those found above 30 meters.

In summary there appears to have been a surprisingly regular succession of population lows during the first part of every month and population highs during the middle to later parts of the month. Dominant phytoplankton genera in January were Stephanodiscus, Cyclotella and Chlamydomonas; in February, Glenodinium, Chlamydomonas and Carteria; in March, Carteria; in April, Hemidinium, Carteria and Chlamydomonas; in May, Fragilaria.

Table 11. Distribution of Phytoplankton versus Depth at Station 4, 30 May.

Depth, Meters	Number per ml	
Surface	Fragilaria	116 (5)*
	Chlamydomonas	52 (6)
	Carteria	36 (4)
	Ceratium	7 (2)
	Planktosphaeria	6 (2)
	Phacotus	4 (1)
5	Fragilaria	22 (7)
	Carteria	71 (5)
	Oocystis	17 (3)
	Glenodinium	11 (3)
	Phacotus	4 (1)
	Ankistrodesmus	4 (2)
10	Fragilaria	76 (4)
	Carteria	56 (4)
	Planktosphaeria	5 (1)
	Glenodinium	5 (1)
	Ceratium	3 (1)
20	Carteria	54 (6)
	Fragilaria	10 (3)
	Cyclotella	5 (1)
	Oscillatoria	3 (1)
30	Carteria	402 (86)
	Glenodinium	278 (66)
	Fragilaria	17 (5)
	Cyclotella	11 (4)
	Navicula	5 (2)
Bottom + 1	Cyclotella	21 (5)
	Fragilaria	20 (3)
	Navicula	7 (3)
	Oscillatoria	4 (2)
	Cymbella	4 (2)

*Numbers in parentheses are standard error.

Physical Factors

Results of determinations of temperature are given in Tables 12 through 18; of oxygen in Tables 19 through 25, and conductivity in Tables 26 and 27. A good summary view of changes occurring in the bay should be obtained by scanning these tables before proceeding with the text.

Temperatures

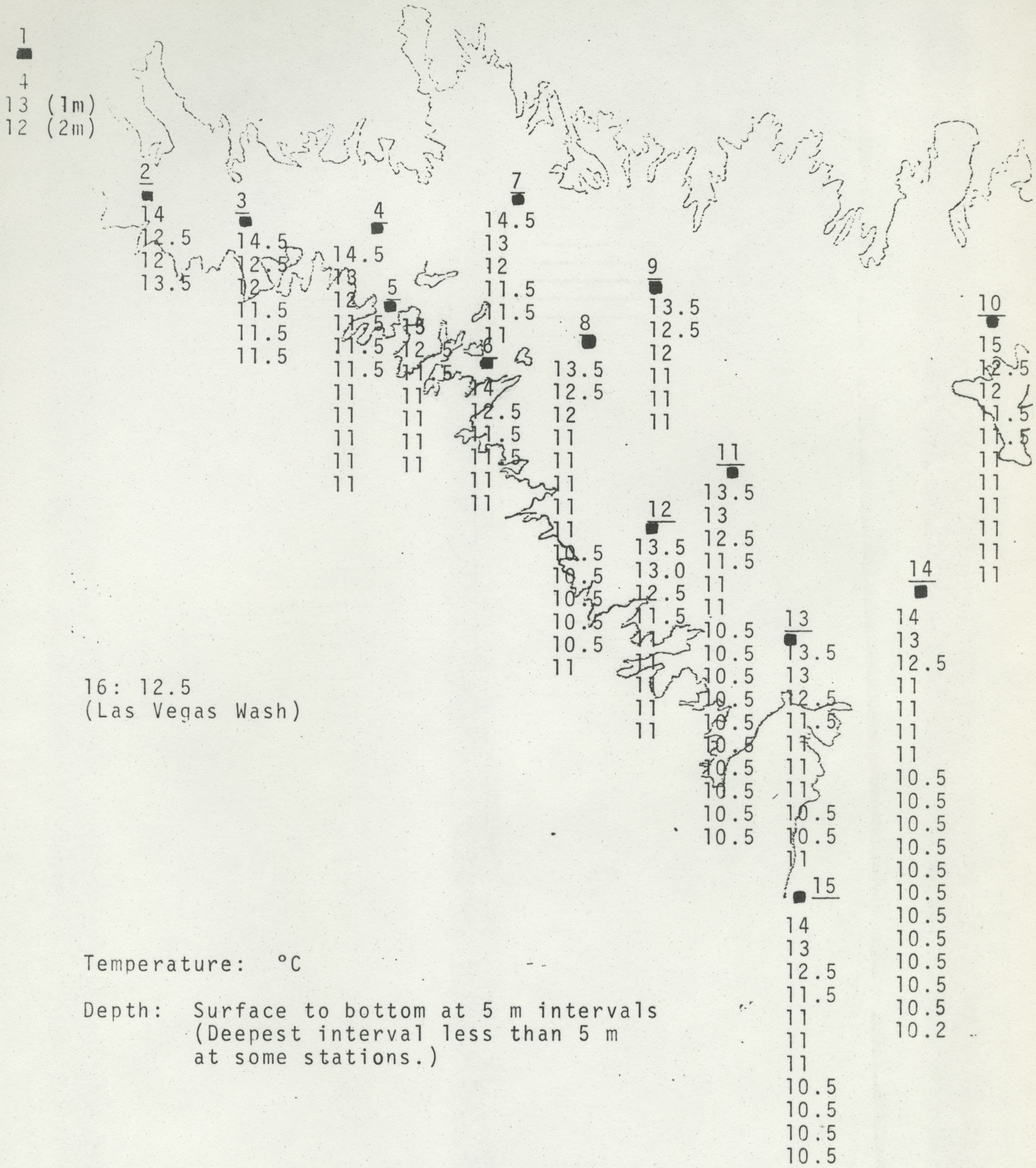
Increasing differential temperatures at Stations 4-14 during the period indicate increasing stability of stratification in the middle and outer bay, with the knee of the thermocline eventually established at 10-15 meters. However, the data indicate a trend toward decreased stability in the inner bay. Note especially the situation at Station 2 on 30 May, (Table 18).

Occasionally, as on 6 and 20 March and 1 April, inversions occurred at depth at inner bay stations; these were probably associated with the density current. Internal seiches were probably present (outer bay stations, 1 May) but were never pronounced. A tendency toward formation of a double thermocline at Station 14 was apparent late in the period. Double thermoclines are common in very deep lakes.

Oxygen

Oxygen curves were orthograde until May 1 when a negative heterograde distribution was found at middle and outer bay center channel stations. This phenomenon is discussed in

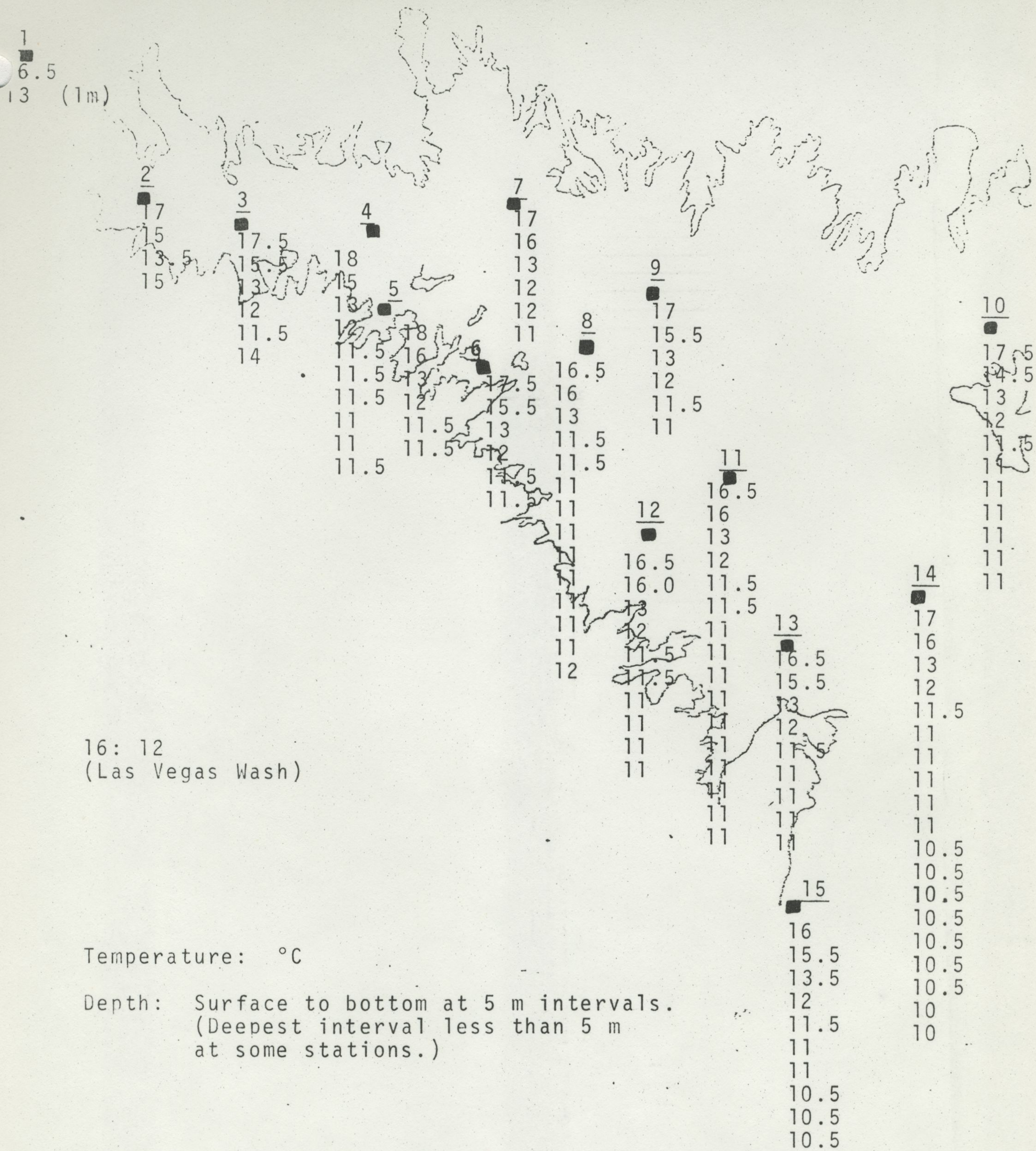
Table 12. Temperatures in Las Vegas Bay, March 6, 1972.



Temperature: °C

Depth: Surface to bottom at 5 m intervals (Deepest interval less than 5 m at some stations.)

Table 13. Temperatures in Las Vegas Bay, March 20, 1973.

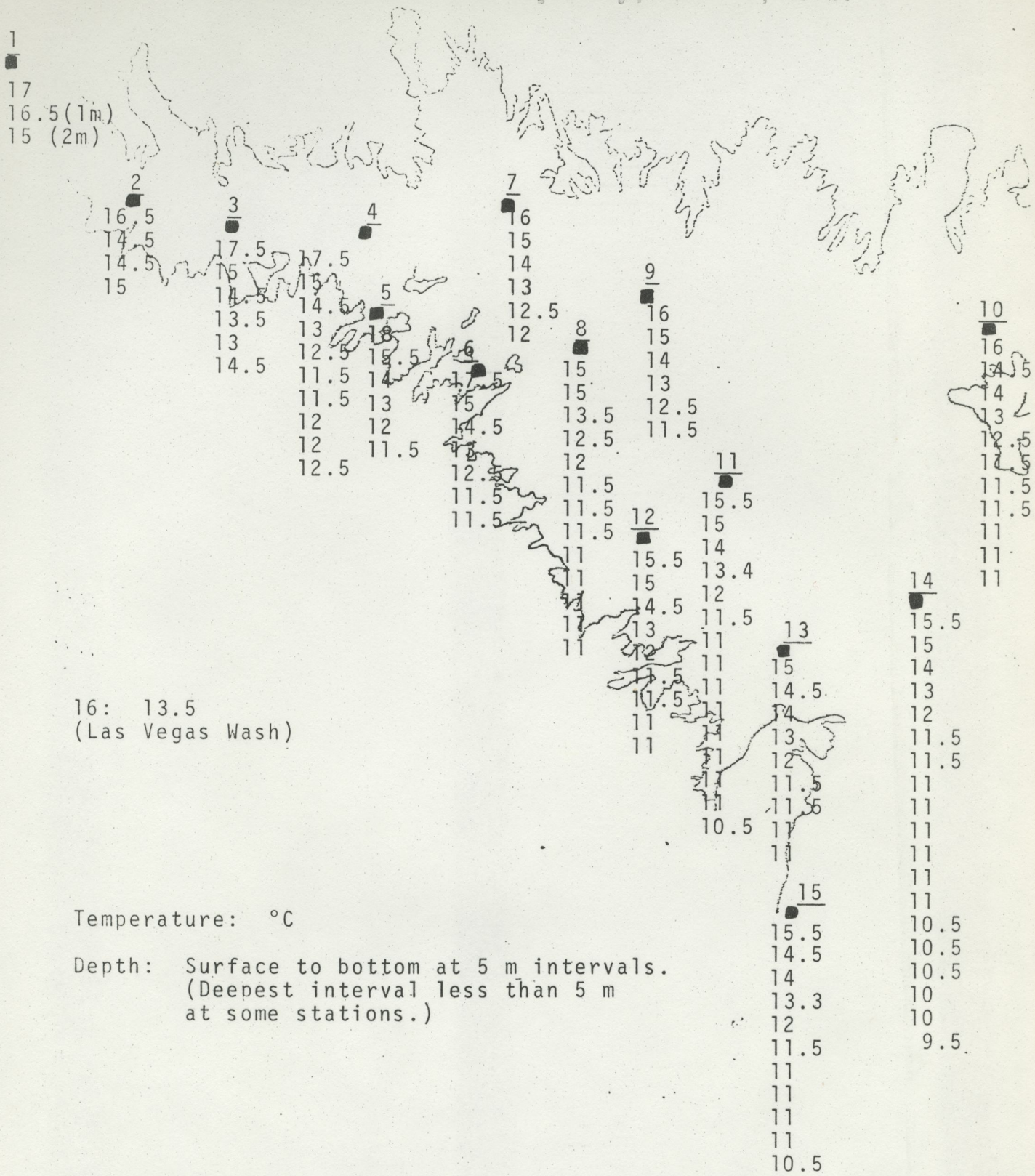


16: 12
(Las Vegas Wash)

Temperature: °C

Depth: Surface to bottom at 5 m intervals.
(Deepest interval less than 5 m
at some stations.)

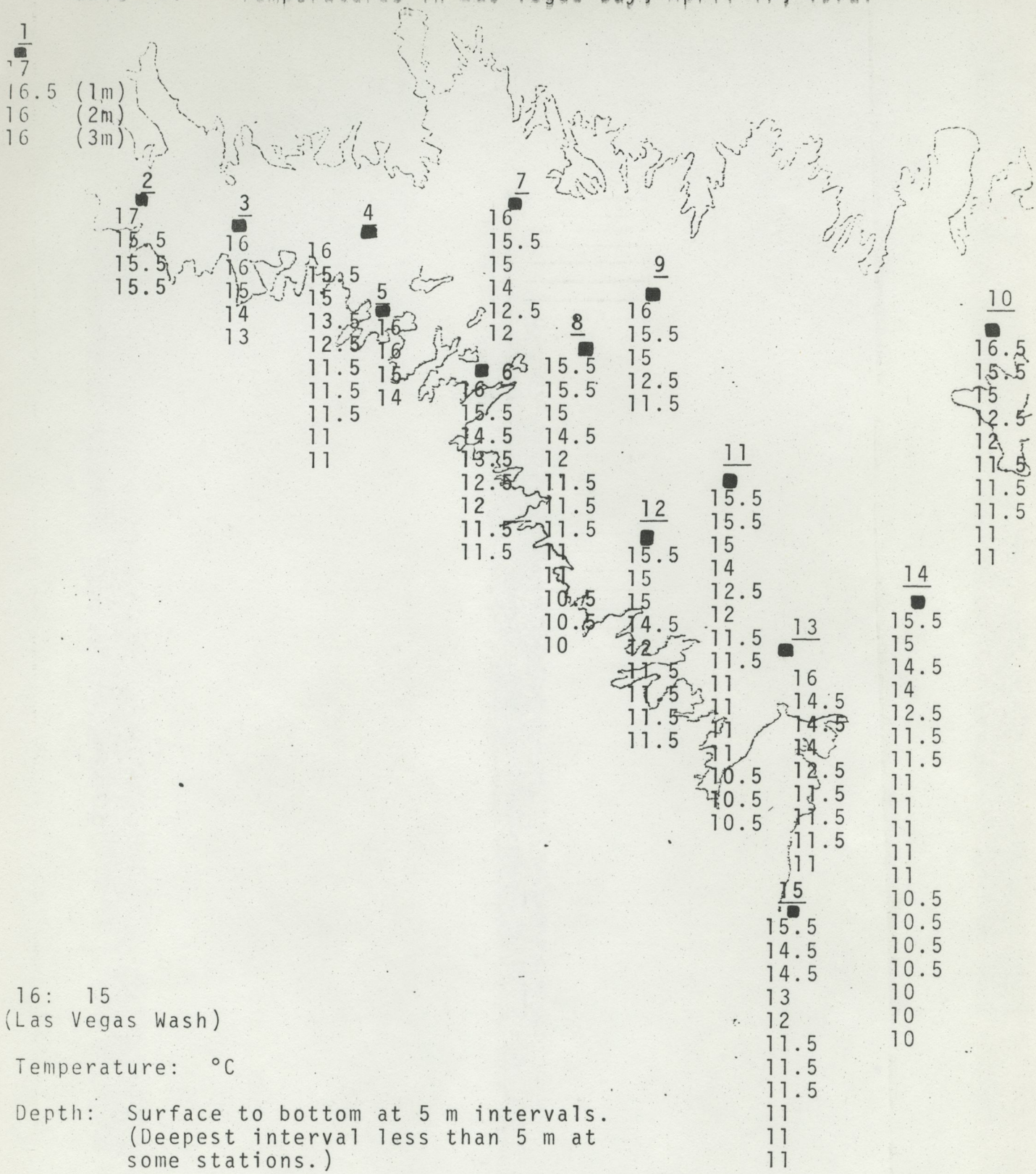
Table 14. Temperatures in Las Vegas Bay, April 3, 1972.



Temperature: °C

Depth: Surface to bottom at 5 m intervals. (Deepest interval less than 5 m at some stations.)

Table 15. Temperatures in Las Vegas Bay, April 17, 1972.

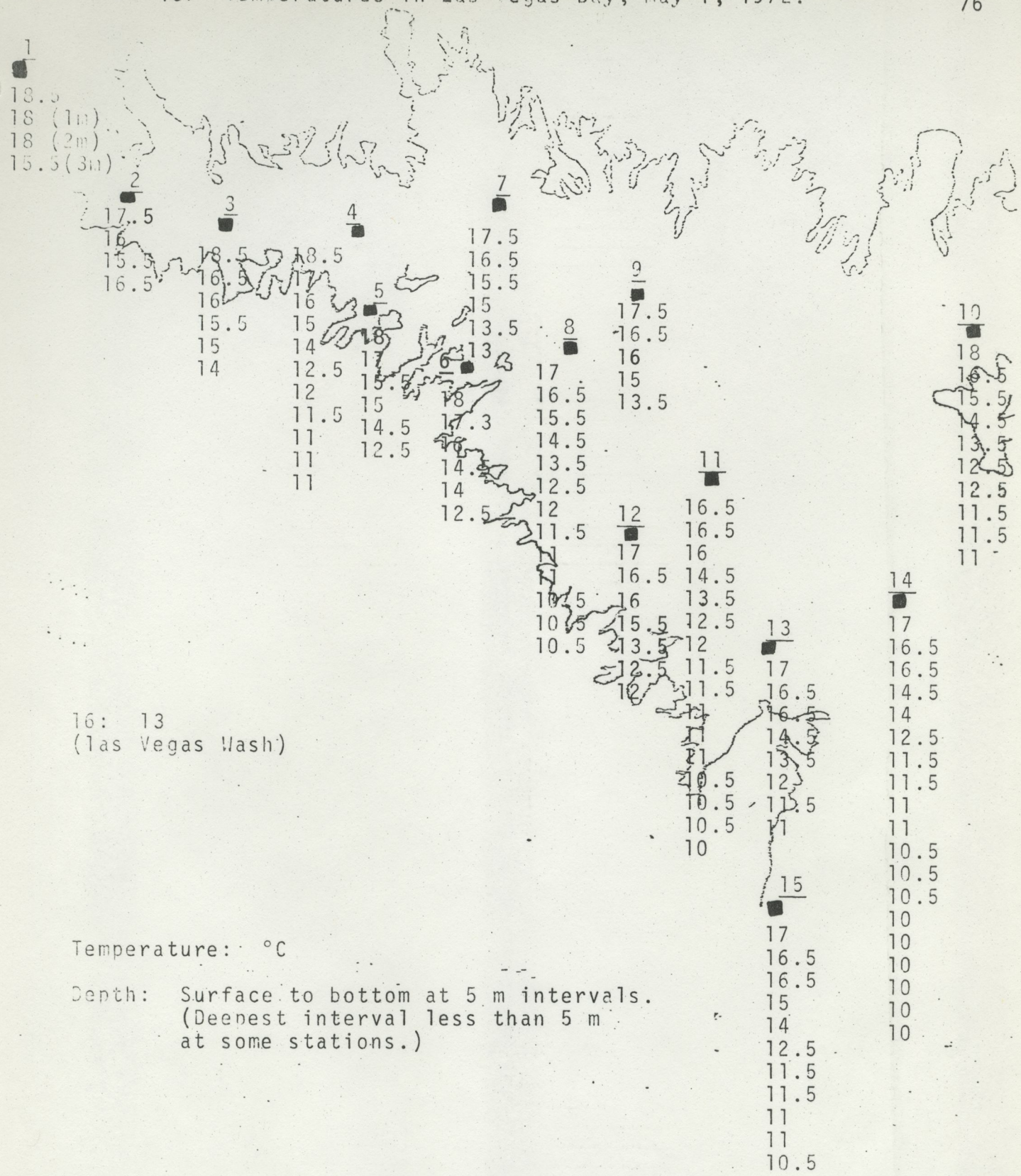


16: 15
(Las Vegas Wash)

Temperature: °C

Depth: Surface to bottom at 5 m intervals. (Deepest interval less than 5 m at some stations.)

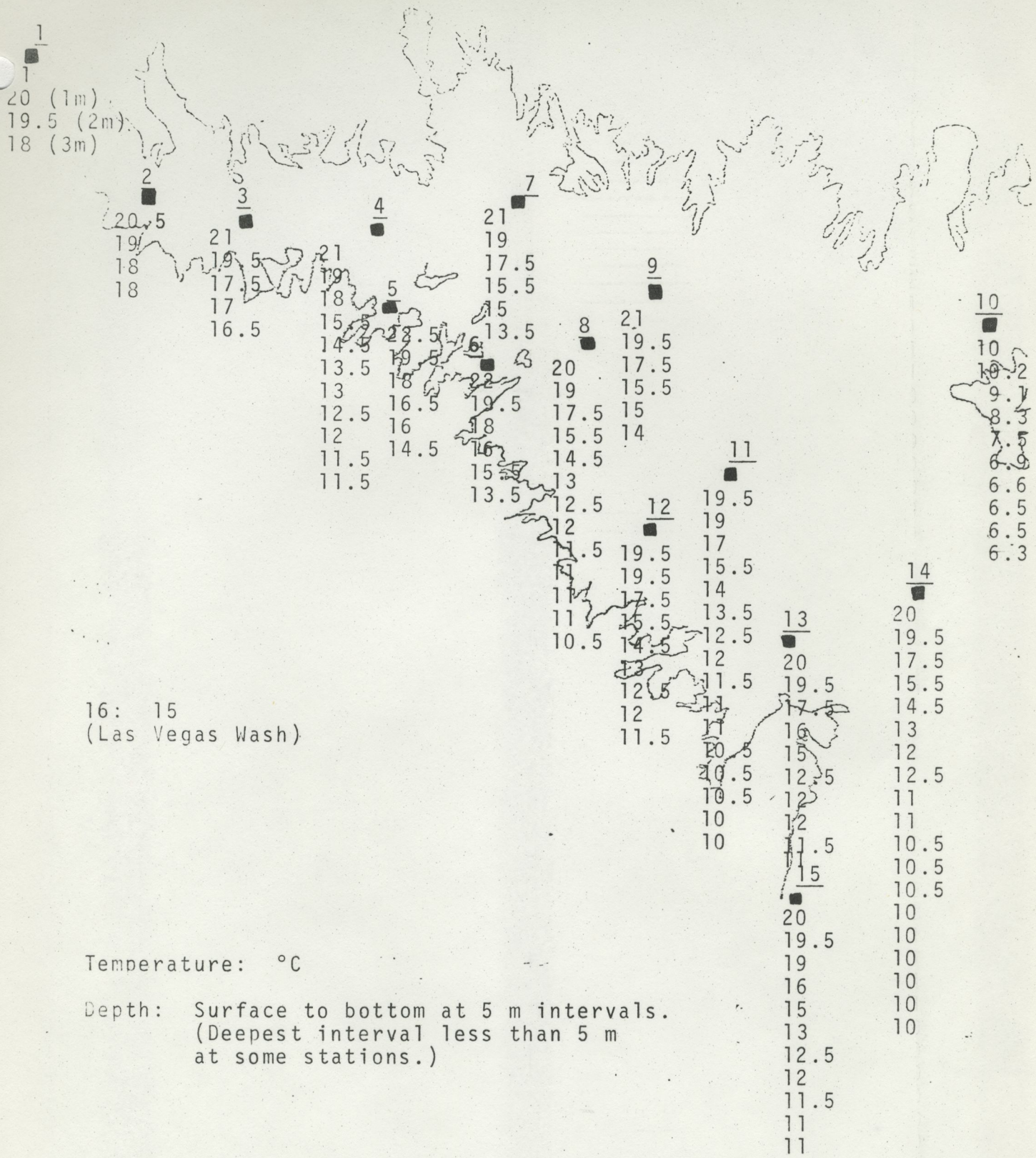
Table 16. Temperatures in Las Vegas Bay, May 1, 1972.



Temperature: °C

Depth: Surface to bottom at 5 m intervals. (Deepest interval less than 5 m at some stations.)

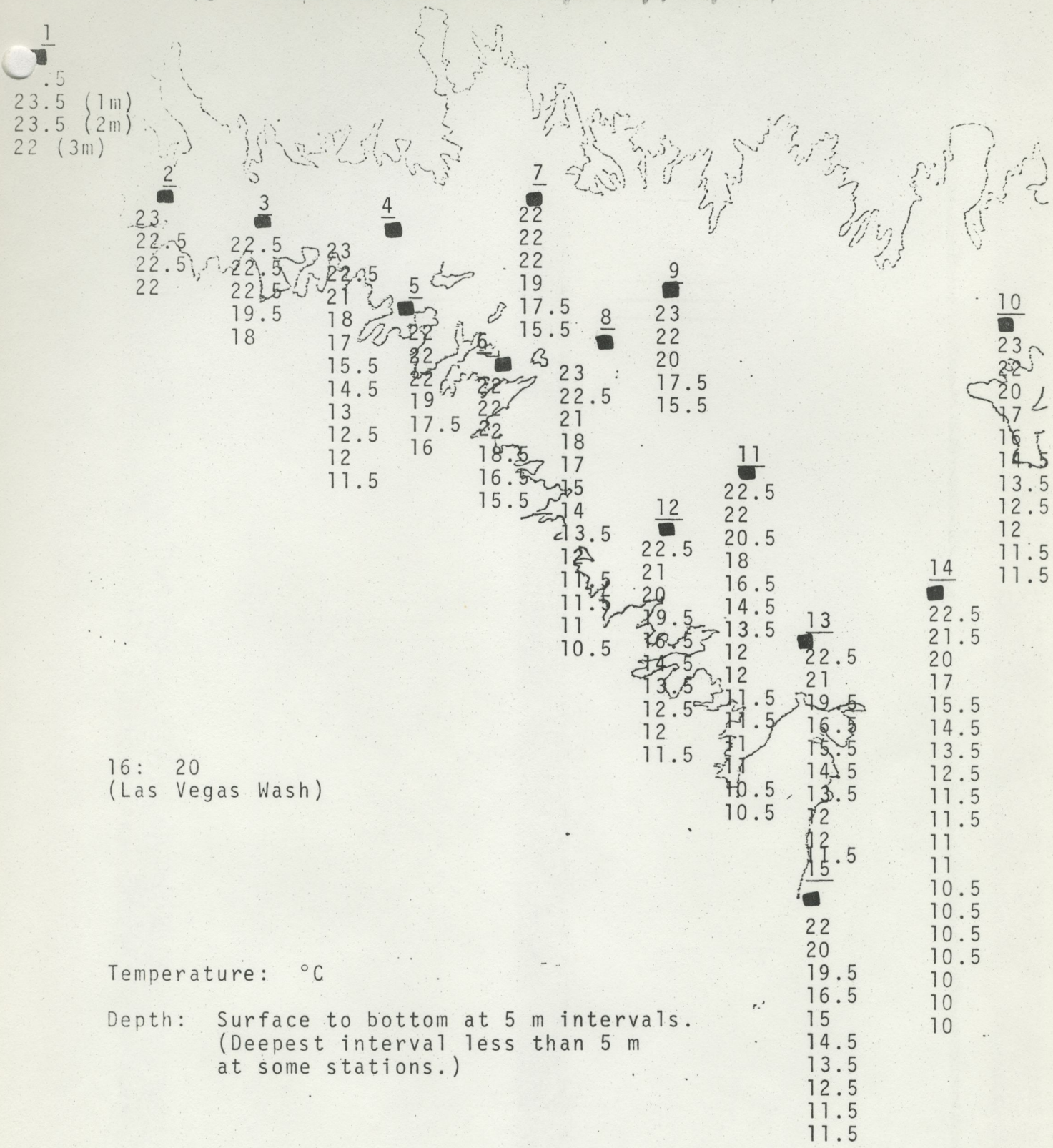
Table 17. Temperatures in Las Vegas Bay, May 15, 1972.



Temperature: °C

Depth: Surface to bottom at 5 m intervals. (Deepest interval less than 5 m at some stations.)

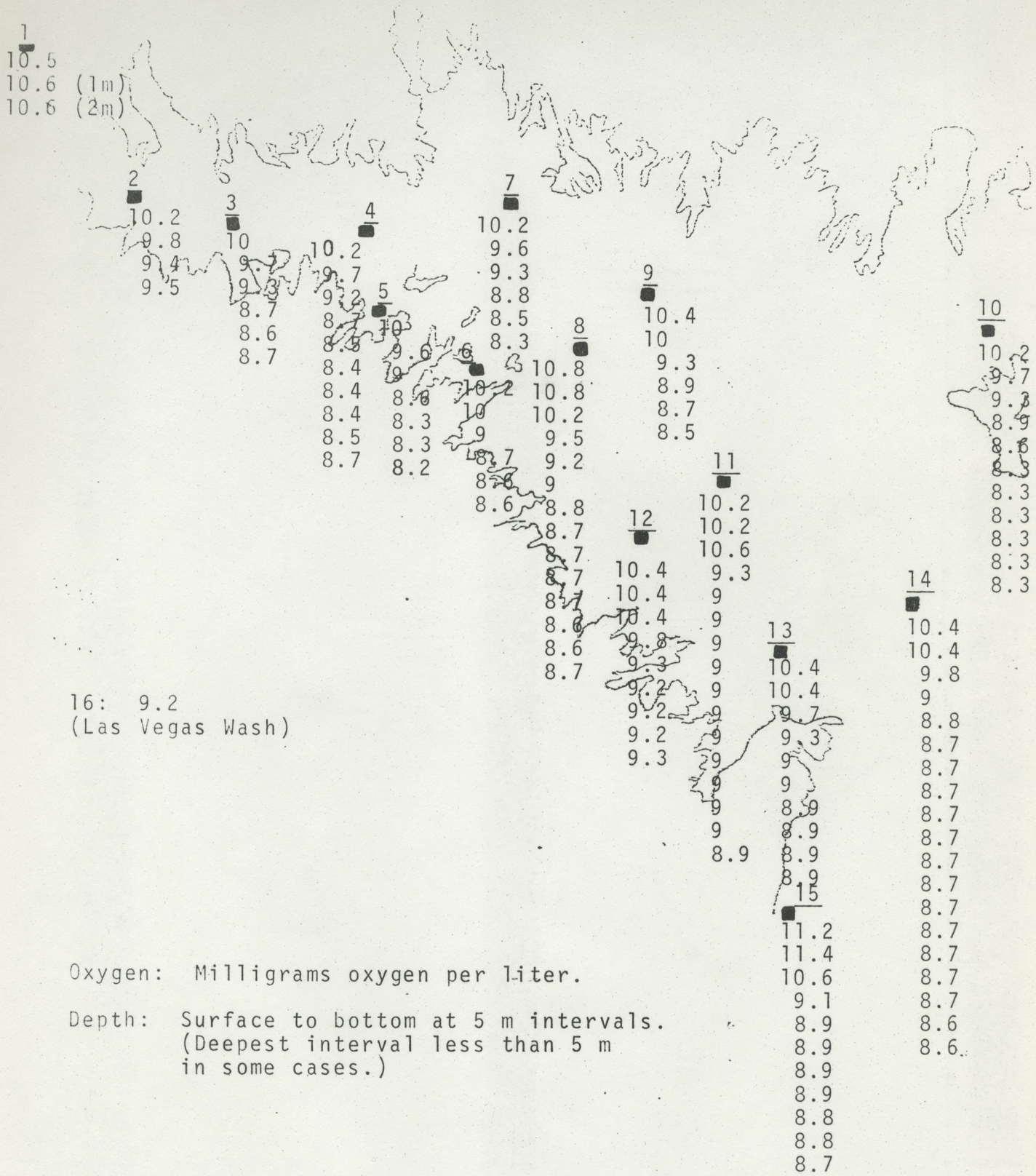
Table 18. Temperatures in Las Vegas Bay, May 30, 1973.



Temperature: °C

Depth: Surface to bottom at 5 m intervals. (Deepest interval less than 5 m at some stations.)

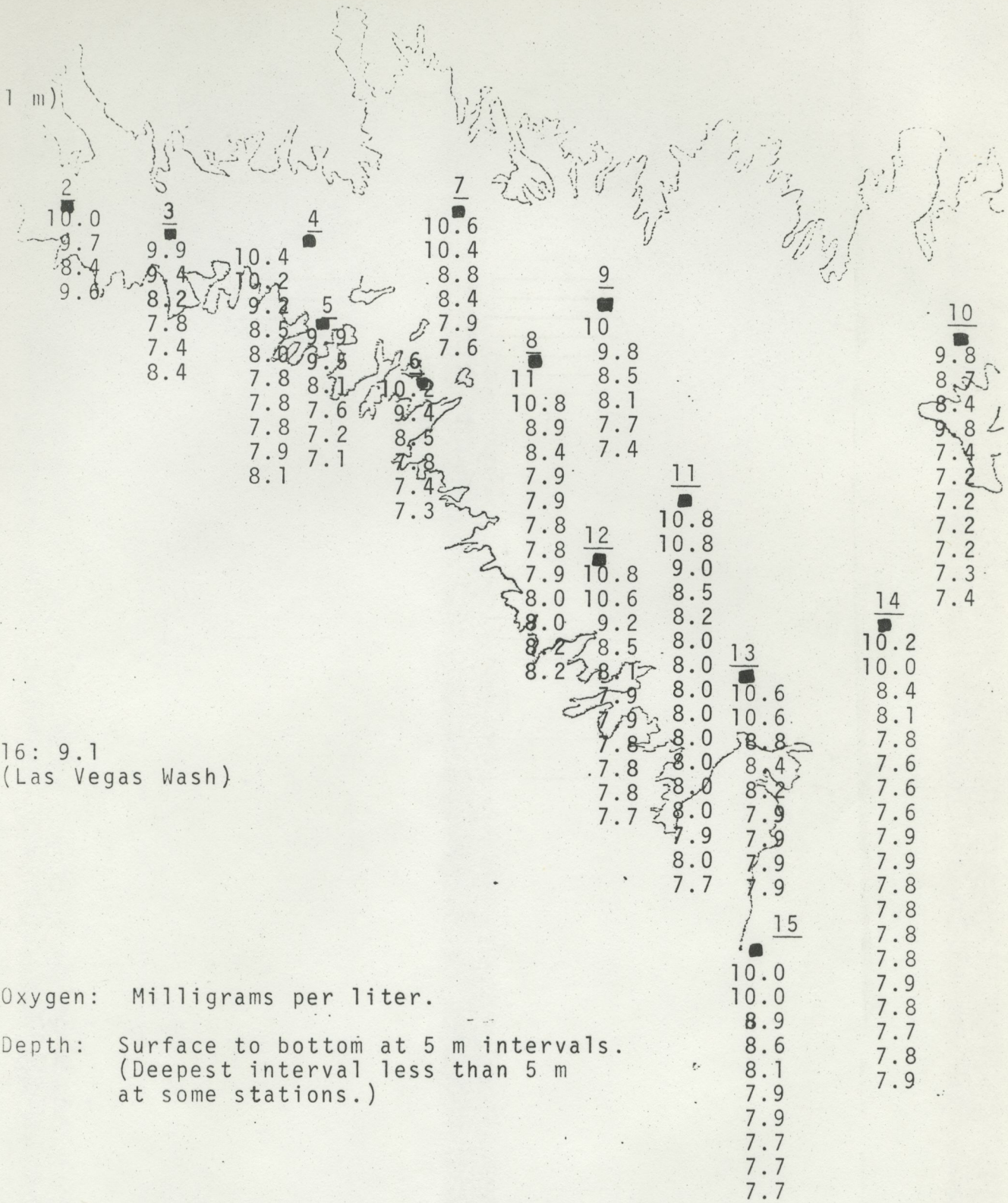
Table 19. Oxygen in Las Vegas Bay, March 6, 1972.



Oxygen: Milligrams oxygen per liter.

Depth: Surface to bottom at 5 m intervals. (Deepest interval less than 5 m in some cases.)

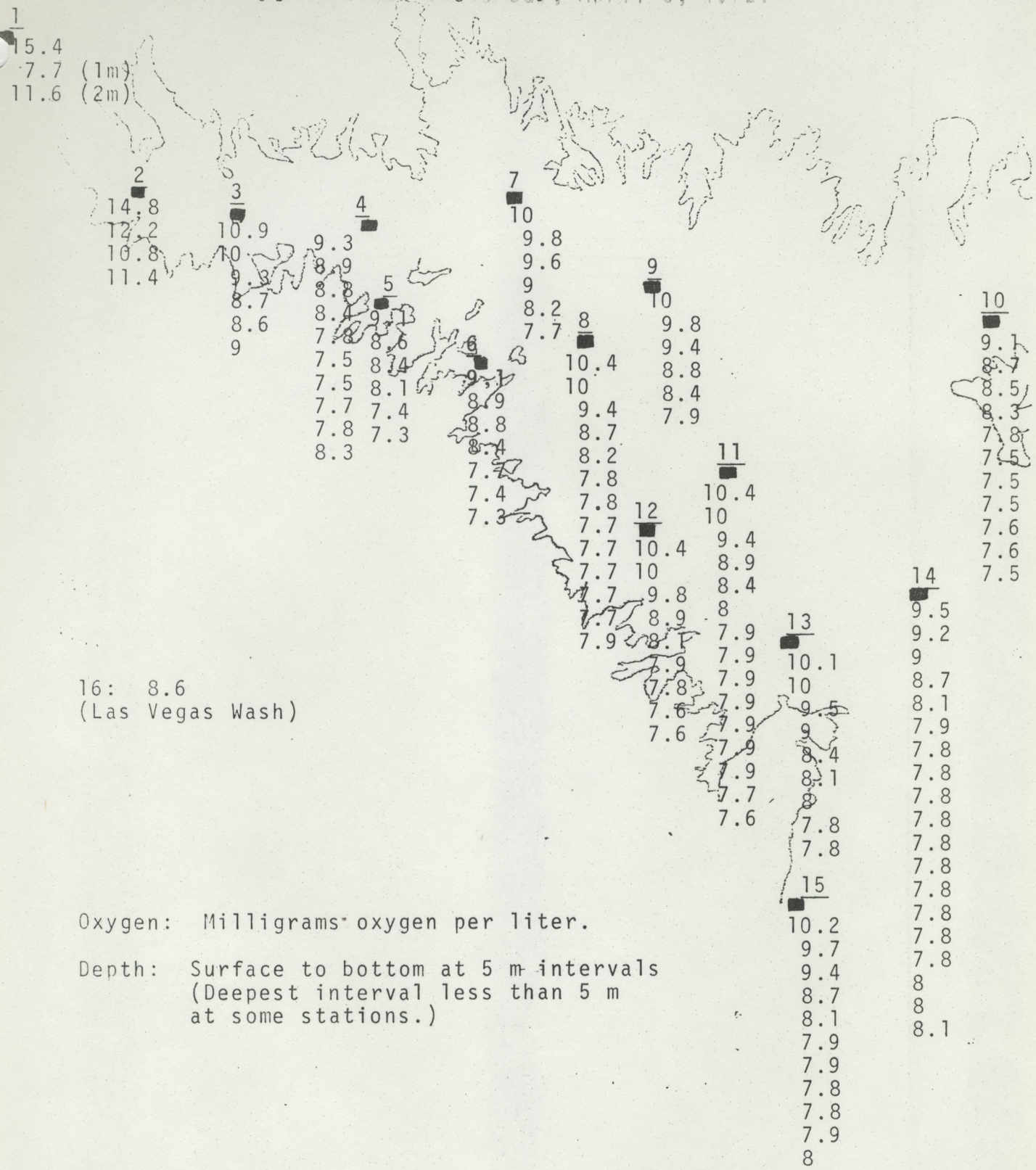
Table 20. Oxygen in Las Vegas Bay, March 20, 1972.



Oxygen: Milligrams per liter.

Depth: Surface to bottom at 5 m intervals. (Deepest interval less than 5 m at some stations.)

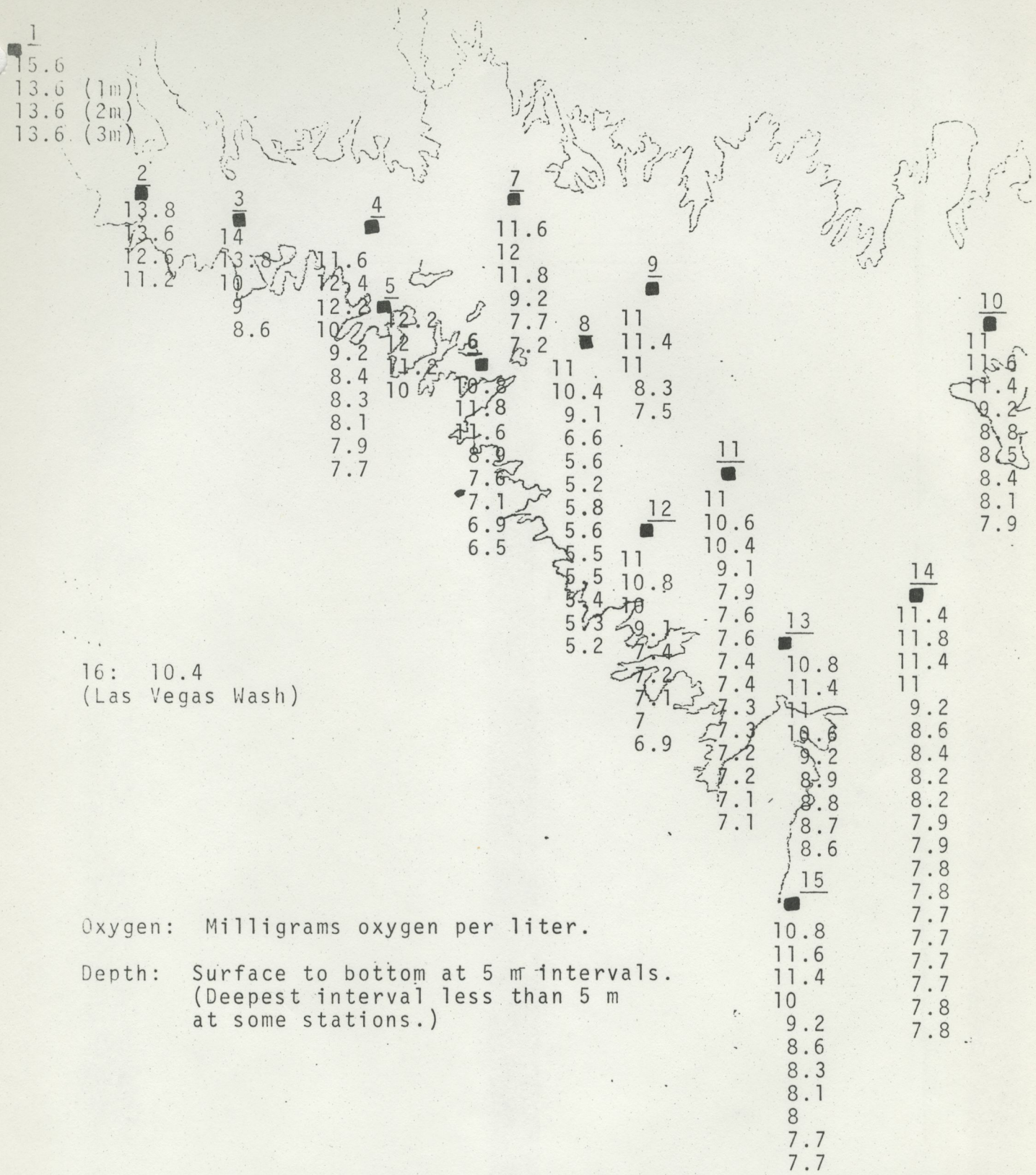
Table 21. Oxygen in Las Vegas Bay, April 3, 1972.



Oxygen: Milligrams oxygen per liter.

Depth: Surface to bottom at 5 m intervals (Deepest interval less than 5 m at some stations.)

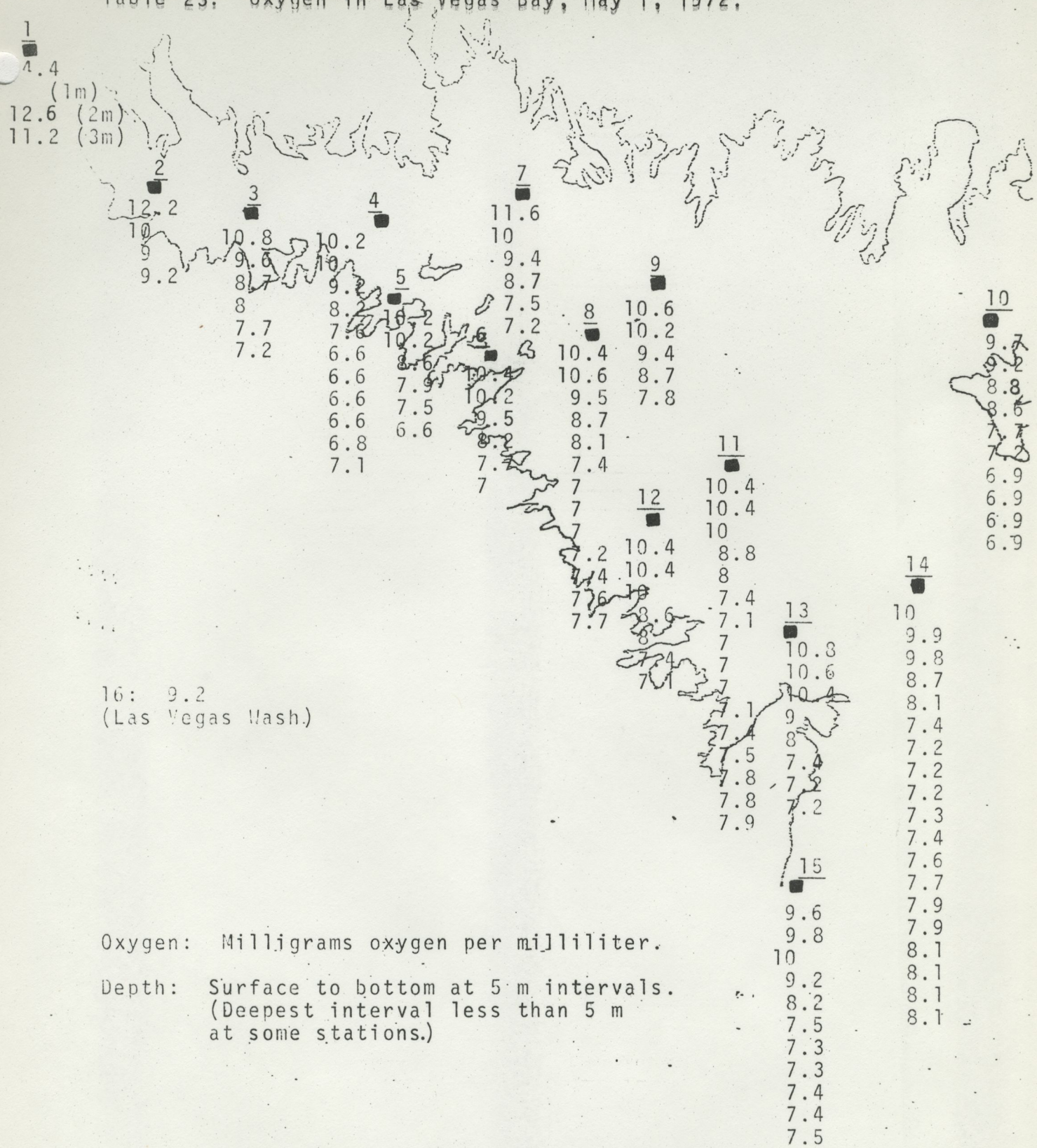
Table 22. Oxygen in Las Vegas Bay, April 17, 1972.



Oxygen: Milligrams oxygen per liter.

Depth: Surface to bottom at 5 m intervals. (Deepest interval less than 5 m at some stations.)

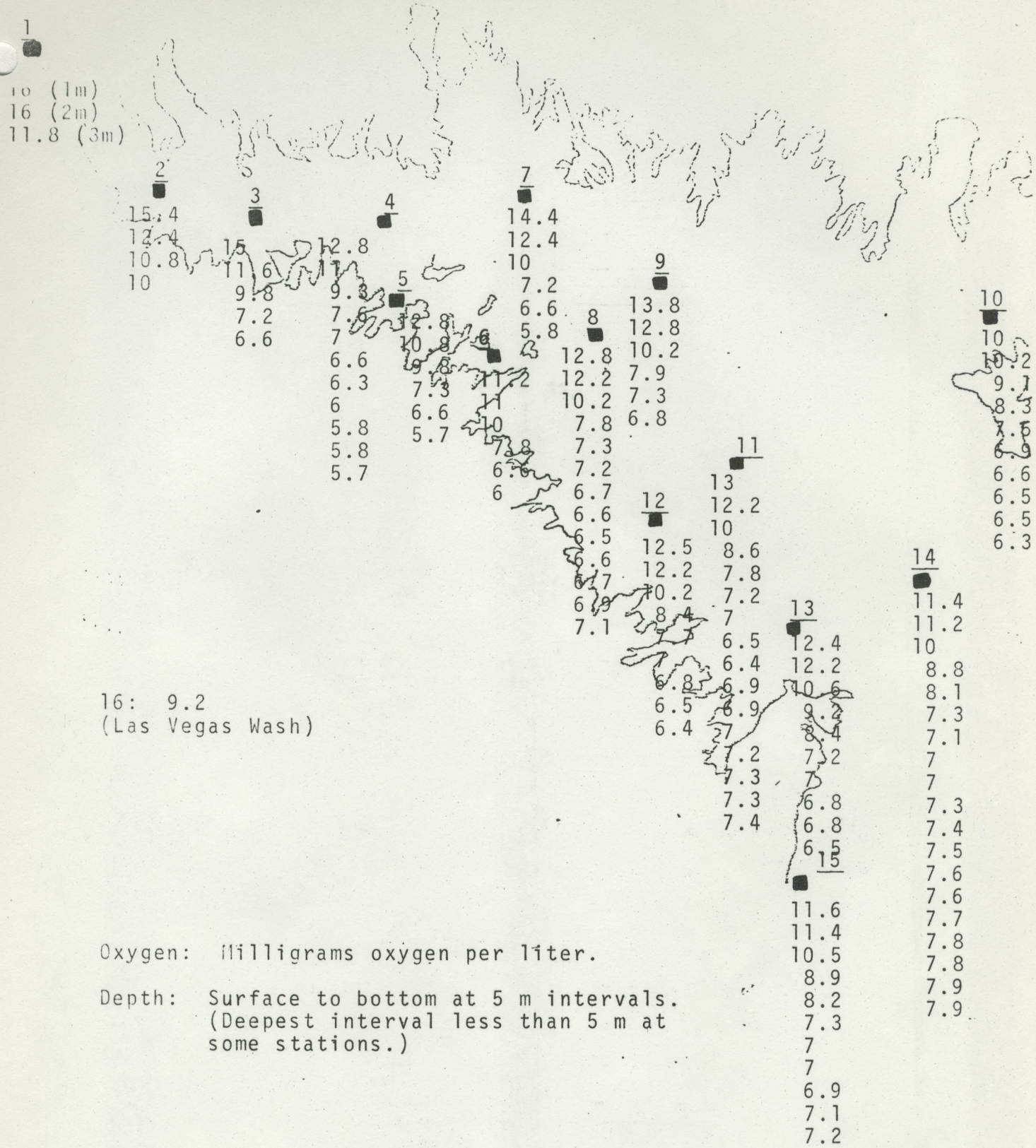
Table 23. Oxygen in Las Vegas Bay, May 1, 1972.



Oxygen: Milligrams oxygen per milliliter.

Depth: Surface to bottom at 5 m intervals. (Deepest interval less than 5 m at some stations.)

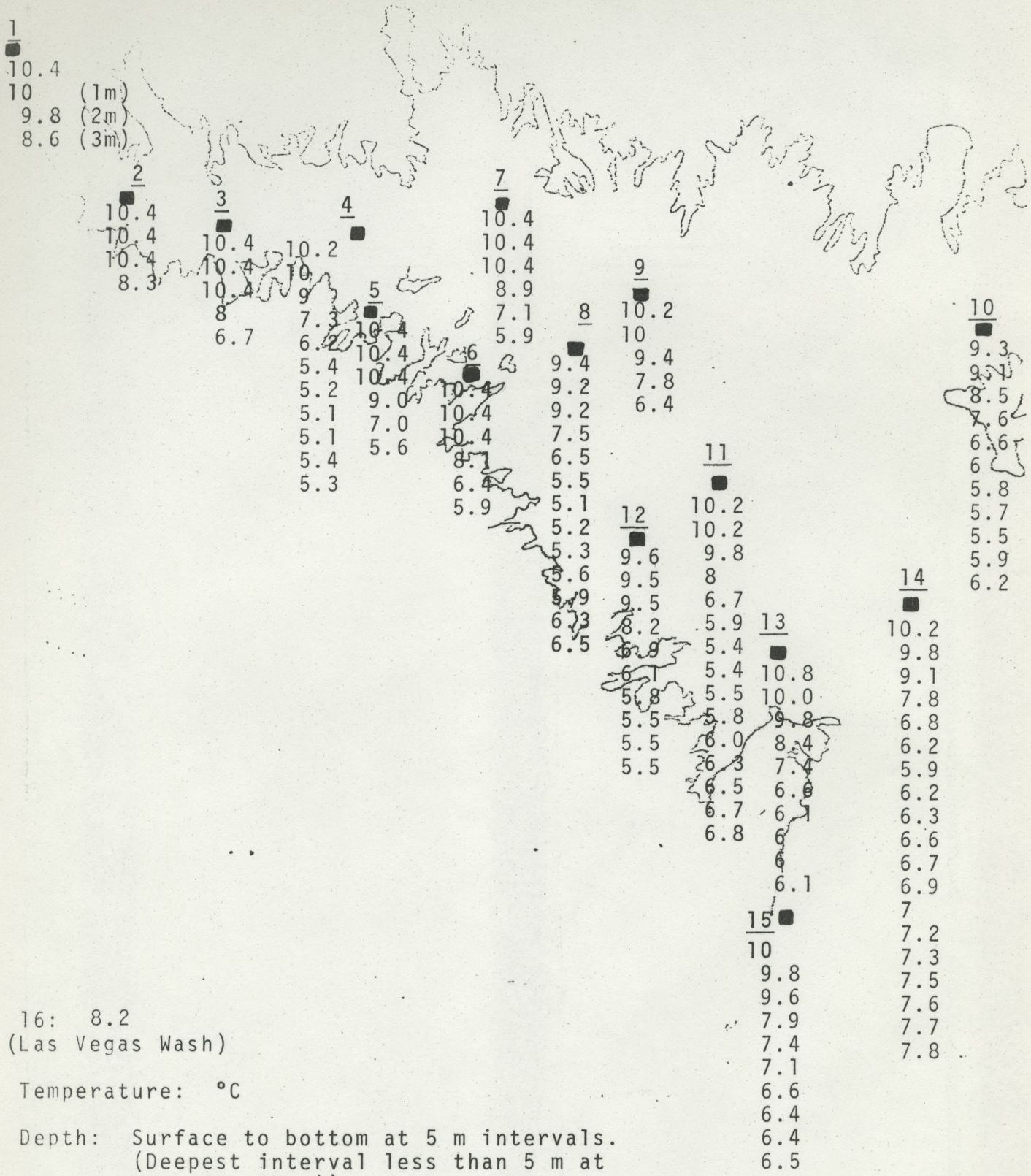
Table 24. Oxygen in Las Vegas Bay, May 15, 1972.



Oxygen: Milligrams oxygen per liter.

Depth: Surface to bottom at 5 m intervals. (Deepest interval less than 5 m at some stations.)

Table 25. Oxygen in Las Vegas Bay, May 30, 1972.



16: 8.2
(Las Vegas Wash)

Temperature: °C

Depth: Surface to bottom at 5 m intervals. (Deepest interval less than 5 m at some stations.)

Table 26. Location of conductivities above 1100 μmoh/cm in Las Vegas Bay, 6 March - 30 May, 1972.

Date	Station	Depth, m	Conductivity, μmho/cm
6 March	1	2*	3800
	2	14*	2800
	3	23*	1500
	4	47*	1500
	8	60	1150
		62*	1350
	11	70	1150
		74*	1200
13 March	1	2*	4200
	2	14*	2600
	3	20	1150
		22*	1500
	4	45	1200
		47*	1450
	8	55	1150
		60	1200
		62*	1450
	11	65	1150
		70-73*	1200
	14	80-90*	1150
20 March	1	1*	4200
	2	14*	2400
	3	23*	1600
	4	45*	1200
	8	50	1150
		55	1200
		60	1350
		61*	1450
	11	60-65	1150
		70	1200
		72*	1220
	14	75-85	1120
		90*	1150
28 March	1	1	1550
		2*	4550
	2	0-10	1150
		14*	2400
	3	20	1250
		22*	1750

Table 26. (cont.)

Date	Station	Depth, m	Conductivity, µmho/cm
28 March	4	30	1150
		35-40	1200
		45	1450
		47*	1650
	8	30-61*	1200
	11	35-72*	1150
3 April	1	1	1250
		2*	4000
	2	10	1150
		13*	2450
	3	20	1500
		22*	1650
	4	35	1200
		40	1300
		45*	1350
	8	45-55	1200
		60*	1350
	11	55	1150
		60-70*	1200
17 April	1	0-1	1150
		2	1200
		3*	3500
	2	10	1200
		13*	2400
	3	15-22*	1300
	4	15-45*	1200
	6	25-32*	1150
	8	25-30	1150
		50-59*	1150
24 April	1	0-2	1200
		3*	3300
	2	10	1200
		13.5*	1800
	3	15	1250
		20-22*	1450
	8	59*	1150
1 May	1	0	1150
		1	1175
		2	1200
		3*	2800

Table 26. (cont.)

Date	Station	Depth, m	Conductivity, μmho/cm
1 May	2	10	1250
		12.5*	2300
	3	15	1250
		20-21*	1450
	4	20	1150
		25-30	1200
	5	20-25*	1250
	7	20-22*	1200
8 May	1	0-1	1150
		2	1200
		3*	2800
	2	10	1750
		12.5*	2450
	3	15	1400
		20	1550
		22*	1600
	4	20-25	1250
		30	1200
		35	1100
		40	1200
		45*	1250
	5	20-24*	1250
	6	21*	1200
	7	20	1200
		22*	1250
	8	30-59*	1150
15 May	1	3*	3800
	2	12.5*	2900
	3	15	1400
		20*	1750
	4	45-46*	1150
	5	20-22*	1350
	6	25*	1150
	7	20	1200
		24*	1250
	8	40-45	1150
22 May	1	2	1200
		3*	3600
	2	10	1200
		15*	2800
	3	15	1150
		21*	1450

Table 26. (cont.)

Date	Station	Depth, m	Conductivity, μmho/cm
22 May	4	20-30	1200
	5	20-24*	1250
	6	20	1150
		25-27*	1200
	7	20	1200
		25*	1250
	8	25-30	1200
		35	1150
30 May	1	1-2	1150
		3*	3100
	2	12.5*	2300
	3	15	1200
		20	1500
	4	20	1200
		25-40	1250
		45	1200
		46*	1100
	5	20	1250
		25*	1400
	6	23*	1150
	8	25-35	1150
	11	25-35	1150

*bottom

Table 27. Temperature and conductivity at Station 16, Las Vegas Wash, and Station 1, Las Vegas Bay, 6 March - 30 May, 1972.

Date	Station 16		Station 1		
	Temperature	Conductivity	Depth, m	Temperature	Conductivity
6 March 72	12.5	4850	0	14	1100
			1	13	1100
			2	12.5	3800
13 March 72	13.5	5000	0	16	1100
			1	15.5	1100
			2	14.5	4200
20 March 72	12	4700	0	16.5	1100
			1	13	4200
28 March 72	8	4800	0	14	1100
			1	14	1550
			2	10.5	4550
3 April 72	13.5	4300	0	17	1100
			1	16.5	1250
			2	15	4000
17 April 72	15	5000	0	17	1150
			1	16.5	1150
			2	16	1250
			3	16	3500
24 April 72	14.5	5150	0	19	1200
			1	18.5	1200
			2	18	1200
			3	17	3300
1 May 72	13	5150	0	18.5	1150
			1	18	1175
			2	18	1200
			3	15.5	2800
8 May 72	16	4700	0	20	1150
			1	20	1150
			2	20	1200
			3	18.5	2800

Table 27. (cont.)

Date	Station 16		Station 1		
	Temperature	Conductivity	Depth, m	Temperature	Conductivity
15 May 72	15	4950	0	21	1100
			1	20	1100
			2	19.5	1100
			3	18	3800
22 May 72	14	4900	0	21	1100
			1	20.5	1100
			2	20.5	1150
			3	17.5	3600
30 May 72	20	4900	0	23.5	1100
			1	23.5	1150
			2	23.5	1150
			3	22	3100

greater detail elsewhere in the text.

Oxygen supersaturation appeared to be correlated with numbers of phytoplankton. For example, note inner bay surface oxygen levels for 1, 15, and 30 May, Tables 23, 24, and 25. Next, consult Figs. 24, 26, and 28 for phytoplankton distributions on these dates and it will become obvious that oxygen concentrations were correlated with the May increase and decline in Fragilaria. Data for March and April suggest the same general conclusions.

Since phytoplankton growth and oxygen production are coupled functions (if the algae are growing essentially as photoautotrophs) the oxygen supersaturations detected probably indicate in situ growth, i.e. of Fragilaria to 15 May, and decline, i.e. Fragilaria 30 May.

The lowest oxygen concentrations noted at bottom surface were on the order of 5 ppm (Station 8, 17 April; Stations 4 and 5, 15 May; Stations 4, 5, 6, 7, and 12, 30 May). Oxygen curves did not become severely clinograde either throughout the hypolimnion, under the negative heterograde distribution (when it occurred) or in the region of the hypolimnion just above bottom. These observations suggest that the surface of the sediments may have remained oxidized, and that iron and phosphate release did not take place. This may explain oligotrophy over most of the lake during the spring and points to the wash as a more important nutrient source than are the sediments.

Conductivity

Conductivity data (Table 26) show that the density current existed uniformly just above the center channel bottom during March. Its stability is shown by observation of above-bottom conductivity discontinuities as far out in the bay as Station 14.

During April and May a condition of intermittent instability could be detected. Conductivity discontinuities became very diffuse, multiple, and began to appear at lateral stations. Note especially the data for 8 May.

The data in Table 27 show the relationship of temperature and conductivity data at Stations 16 (wash) and 1. The conductivity results indicate a trend toward greater mixing after 17 April.

The consistently lower temperatures recorded for Station 16 than above bottom at Station 1 may reflect the actual time of data collection rather than mixing, and point out a weakness in the sampling scheme. Continuously recorded data should have been taken on at least one date in May to indicate the effect of diurnal temperatures on the fate of the flow from the wash.

Conclusion for this Period

Physical data substantiate but do not prove the hypothesis that increased mixing of the flow from the wash with the water of the inner bay after 1 April brings about marked increases in

phytoplankton growth rates in the inner bay.

The absence of a clinograde oxygen curve near the sediment surface suggests that nutrient releases are not occurring from the bottom sediments.

Summer Plankton Maxima

Biotic Factors

A large increase in Fragilaria during May began at the point of juncture of the Wash and the Bay (850 colonies per ml on 15 May) and signaled conversion of the eiplimnion to mildly eutrophic conditions.

Numbers of Fragilaria colonies were somewhat less numerous in the middle bay (250-500 colonies per milliliter out to Sand Island). However, the outer bay remained in an oligotrophic condition.

During June large populations of colonial green algae succeeded the Fragilaria. These organisms originated in the inner bay. Subsequently a "wave" of increase and decline moved steadily outward into the outer bay and lake, with 2700 colonies per milliliter observed near the Water District intake structure on 19 June. Implied in the data is a mechanism for transference of nutrient in algal cells throughout the epilimnion from the point of juncture with the wash to the body of the lake.

In July and August, maxima of Cyclotella, a diatom, and Anabaena, a bloom-forming blue-green algae, followed the disappearance of colonial green algae. Increase in Cyclotella and

Anabaena was first noted in the inner bay, and reached greatest numbers there (53,850 Cyclotella cells and 900 Anabaena colonies per ml near Las Vegas Bay Marina on 24 July). Populations were high throughout the bay, with 8000 Cyclotella per ml observed at Station 11, between Sand Island and the juncture of the bay and the lake.

This succession in populations seemed one of the most important biological events recorded during the program. Thus, it seemed especially pertinent to insure that identifications were correct. Accordingly, samples were forwarded to Dr. G. W. Prescott of the University of Montana biological station at Flathead Lake. His comments confirmed the identifications made by program personnel (Table 28). In figures showing plankton distributions by week, Cyclotella species listed as common by Dr. Prescott are grouped as "Cyclotella 2", and the species found on 3 July designated "Cyclotella 1".

A summary of events by week is as follows:

1. July 3. (Fig. 34). Carteria was still the most numerous organism present at Stations 1, 2 and 3 in the inner bay. However, total numbers of this and other algae were less than on 26 June.

In the middle and outer bay, colonial green algae were still dominant, though also less numerous than on 26 June. The only points showing increases were Station 15 in the main body of the lake, and a Las Vegas Marina sample.

Table 28. Phytoplankton collected during early July 1972 in Las Vegas Bay and identified by Dr. G. W. Prescott.

Chlorophyta

- *Scenedesmus quadricauda* (Turp.) Breb.
- *Scenedesmus brevispinus* (Smith) Chodat
- *Scenedesmus acuminatus* (Lag.) Chodat
- *Tetraedron minumum* (A. Braun) Hansg.

Pyrrophyta

- *Glenodinium* sp.
- *Peridinium quadridens*

Cyanophyta

- *Anabaena* sp. (probably A. circinalis - Kuetz.) Rab.
- *Gloeocystis* sp.

Chrysophyta

- *Cyclotella atomus* (common)
- *Cyclotella glomerata*
- *Cyclotella* sp.
- *Eunotia* sp.
- *Fragilaria* sp.
- *Navicula* sp.
- *Synedra ulna*
- *Synedra* sp.

Apparently, the customary monthly decline was taking place in the bay. As shown in Table 29, the colonial green algae (at least at Station 4) had fallen to a point of equal density in the metalimnion, eventually to sink through the hypolimnion to the sediments.

Table 29 also shows the distribution of motile flagellates in the water column. Note the distribution of Glenodinium with a maximum at 10 meters and few or none below 20 meters, both on 3 and 10 July. Phacotus was also most numerous at 10 meters, but could be found all the way from the surface to the bottom at 44 meters. Glenodinium and Phacotus have been persistent throughout the month. Thus, although concentration at 10 meters may represent sinking cells, chemotaxis or response to other stimuli also seems possible. In this case remarkable adaptability of Glenodinium, Phacotus, and Carteria, and a capacity for heterotrophic metabolism, are implied.

Samples from 44 meters contained diatoms found almost always in Las Vegas Wash but not elsewhere in surface samples. Perhaps sediment surface counts of Epithemia, Gomphonema, and Surirella or Nitzschia would be helpful in determining the fate of inflowing water from the Wash.

2. July 10. This date marks the beginning of the Cyclotella bloom. Note that these organisms were found only at Stations 1, 2 and 3, and not at other shallow points, or in the water column at Station 4 (Table 29). This indicates that the

Table 29. Distribution of Plankton with Depth, 3 and 10 July, 1972, Station 4.

	3 July		10 July	
Depth, M	Genus	Numbers/ml	Genus	Numbers/ml
0	Chlamydomonas	217	Anabaena	143
	Carteria	155	Carteria	131
	Glenodinium	88	Glenodinium	28
	Cyclotella, Species 1	27	Cyclotella, Species 1	24
	Phacotus	3		
5	Glenodinium	112	Carteria	96
	Chlamydomonas	96	Anabaena	81
	Carteria	48	Glenodinium	39
	Phacotus	11	Cyclotella 1	31
10	Colonial Greens	1,704	Glenodinium	119
	Glenodinium	108	Carteria	58
	Carteria	82	Anabaena	37
	Phacotus	50	Cyclotella 1	17
15	Colonial Greens	920	Glenodinium	37
	Glenodinium	38	Fragilaria	33
	Carteria	24	Carteria	26
	Phaxotus	13	Cyclotella 1	9

Table 29. (cont.)

Depth, M	Genus	Numbers/ml	Genus	Numbers/ml
20	Colonial Greens	460	Glenodinium	16
	Glenodinium	14	Carteria	8
	Carteria	7	Cyclotella 1	5
	Oscillatoria	4	Fragilaria	5
30	Colonial Greens	292	Carteria	57
	Fragilaria	57	Cyclotella	40
	Phacotus	17	Fragilaria	26
	Cyclotella 1	16	Asterionella	5
44*	Cyclotella	16	Fragilaria	25
	Fragilaria	13	Stephanodiscus	22
	Phacotus	5	Cyclotella 1	17
	Stephanodiscus	5	Cymbella	4
	Synedra	4	Navicula	3
	Oscillatoria	4	Synedra	2
	(Also: Epithemia, Gomphonema, Carteria.)		(Also: Epithemia, Gomphonema, Surirella, Asterionella.)	

*Debris prevented enumeration of plankton other than diatoms and Phacotus.

Note: Except for data for 44 meters, only the 4 most numerous species are shown.

origin of this particular population maximum was associated with the Wash.

As in June, a planktonic blue-green algae, Anabaena circinalis, appeared, but in far fewer numbers than Cyclotella. Anabaena decreased in numbers with distance from the mouth of the Wash, and was present in significant numbers only in the region above 10 meters.

Note the persistence of Glenodinium and Carteria, and the extinction of the colonial green algae.

Although not yet numerous enough to be plotted, Navicula was distributed throughout the bay.

3. June 17 and 24. These figures should be observed together so the enormous development of Cyclotella may be appreciated.

On 12 June, the organisms seemed to have a predilection for the center stations; on the 24th the distribution was more regular. On both days, by far the greatest numbers were found in the inner bay.

Anabaena, unicellular Fragilaria, and Navicula appear as satellites, much as Microcystis did during the previous month. Again, Carteria and Glenodinium persisted at most stations.

After a brief decline in early August, Cyclotella and Anabaena again produced a maximum, though not as spectacular as that recorded in July (18,700 Cyclotella per ml at the junction of the wash and the bay on 5 September). Although Cyclotella was less numerous as distance from the wash increased, Anabaena

was more evenly distributed, with 50-200 colonies noted at almost every station. An anomalously high population of 580 colonies was noted at Station 4, in the middle bay between Las Vegas Marina and Sand Island, also refer to Figs. 29-44.

Physical Factors

A negative heterograde oxygen profile developed during May and June, with oxygen concentrations lowest in the 20-30 meter region, below the knee of the thermocline. The degree of oxygen depletion appeared to be correlated with surface plankton populations and with sonar evidence for large numbers of fish in the zone of depletion itself. Numbers of total viable bacteria correlated with the thermocline and zone of depletion, but at most were rather low, with 5900/ml at 15 meters being the highest population noted on 10 July. At this time no coliform bacteria were found in the upper epilimnion. At 10, 15, 20, 30, and 44 meters at Station 4, 6, 33, 35, 18, and 50 coliforms per ml were observed. Whether these bacteria originated from fish or from the wash is not known. However, the data indicate lack of transfer of coliform bearing water across the thermocline, and correlation of numbers with the negative heterograde oxygen curves. Additional examination of the zone of oxygen depletion is presented later in this report.

The density current rose from the bottom during this period and on 24 July, could be detected just below the knee of

the thermocline, which prevailed fairly uniformly at 10 meters. The following table is illustrative of the situation.

Station	Las Vegas Wash	1	2	3	4
Location of Current, meters		6	10-12.5	15	15-20
Surface Conductivity, m m hos/cm^2		1150	1030	1050	1050
Current Conductivity	4300-5150	3100	1300-2200	1400	1100
Conductivity below Current	Current throughout vertical column	(current above bottom)	(current above bottom)	1000	1000

Note that the current is above the thermocline until it reaches a point between Stations 2 and 3. Here, gain of nutrients by the epilimnion could and probably did occur. Beyond Station 3, the current was still too close to the epilimnion to justify a conclusion that surface waters were not being enriched by nutrients from the current. Influence of water from Las Vegas Wash is easily evident.

During this critical period, tracer studies are needed to quantify the percentage distribution of nutrients from Las Vegas Bay between epilimnion and hypolimnion. However, it seems obvious that enrichment of the epilimnion must occur principally in the inner bay.

Note also that the shallow epilimnion is of far lesser volume than the whole mass of the bay, hence addition of nutrients

to surface waters must result in much more pronounced enrichment effects than additions to the entire bay volume during the Mixing Condition, or during Spring Oligotrophy, when the current is found only just above the bottom.

As has been mentioned previously and illustrated in Fig. 46, oxygen depletion is a rare event at the sediment surface but relatively common in the thermocline during the course of the year.

Return to Mixing Conditions

Biotic Conditions

Deepening of the epilimnion during the fall was accompanied by a slow return to an oligotrophic condition. Algae continued to be relatively more numerous in the inner bay but numbers declined to less than 500 cells per ml for all genera present at middle and outer bay stations in early November. At inner bay stations numbers ranged up to 1258 cells of Cyclotella per ml at Station 1, down considerably from the high levels reached in July and again in September. During this period throughout the bay the overwhelming predominance of Cyclotella diminished while the abundance of Carteria remained much more stable. Anabaena also declined markedly in abundance. The shift then seems to involve a declining abundance of Cyclotella and Anabaena plus a relative stability in abundance of Carteria and Glenodinium resulting in a November population in which dominant positions are held by Cyclotella, Carteria, Glenodinium

and Anabaena. Anabaena maintains a relatively more prominent position in the middle and outer bays than in the inner bay however.

By early November the thermocline had been lowered from 10-15 meters in the summer to 35-45 meters in late fall. This combination of cooling temperatures with increasing volume of the epilimnion is associated with declining phytoplankton populations. The density current, still detectable nearly to Station 3 returned to a position just above the bottom. For brief periods during the return to mixing the sediment surface may show oxygen depletion as the lowering thermocline intersects the bottom. This situation is transitory however and probably occurs infrequently and briefly and therefore is of minimal significance with respect to nutrient regeneration from bottom sediments.

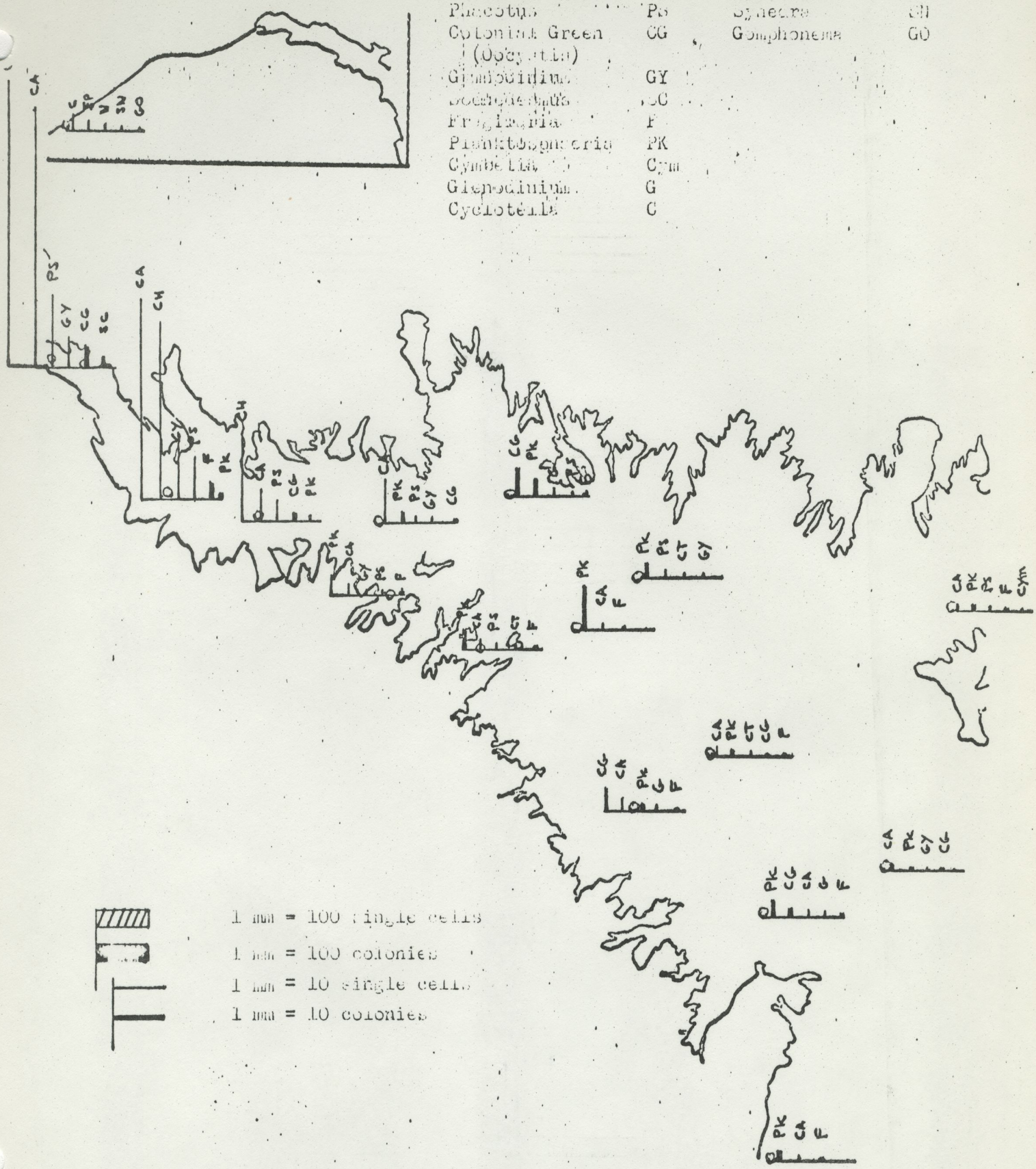
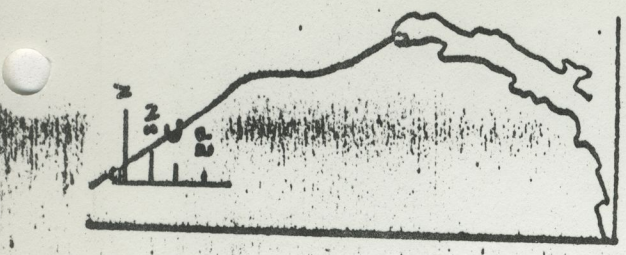


Fig. 29.
Plankton in Las Vegas Bay 6/5/72

Colonial Green	CG
Carteria	CA
Phacotus	PS
Glenodinium	G
Navicula	N
Ceratium	CT
Scenedesmus	SC
Anacystis	AN
Hemidinium	HE
Synedra	SN
Cyclotella	C
Epithemia	EP



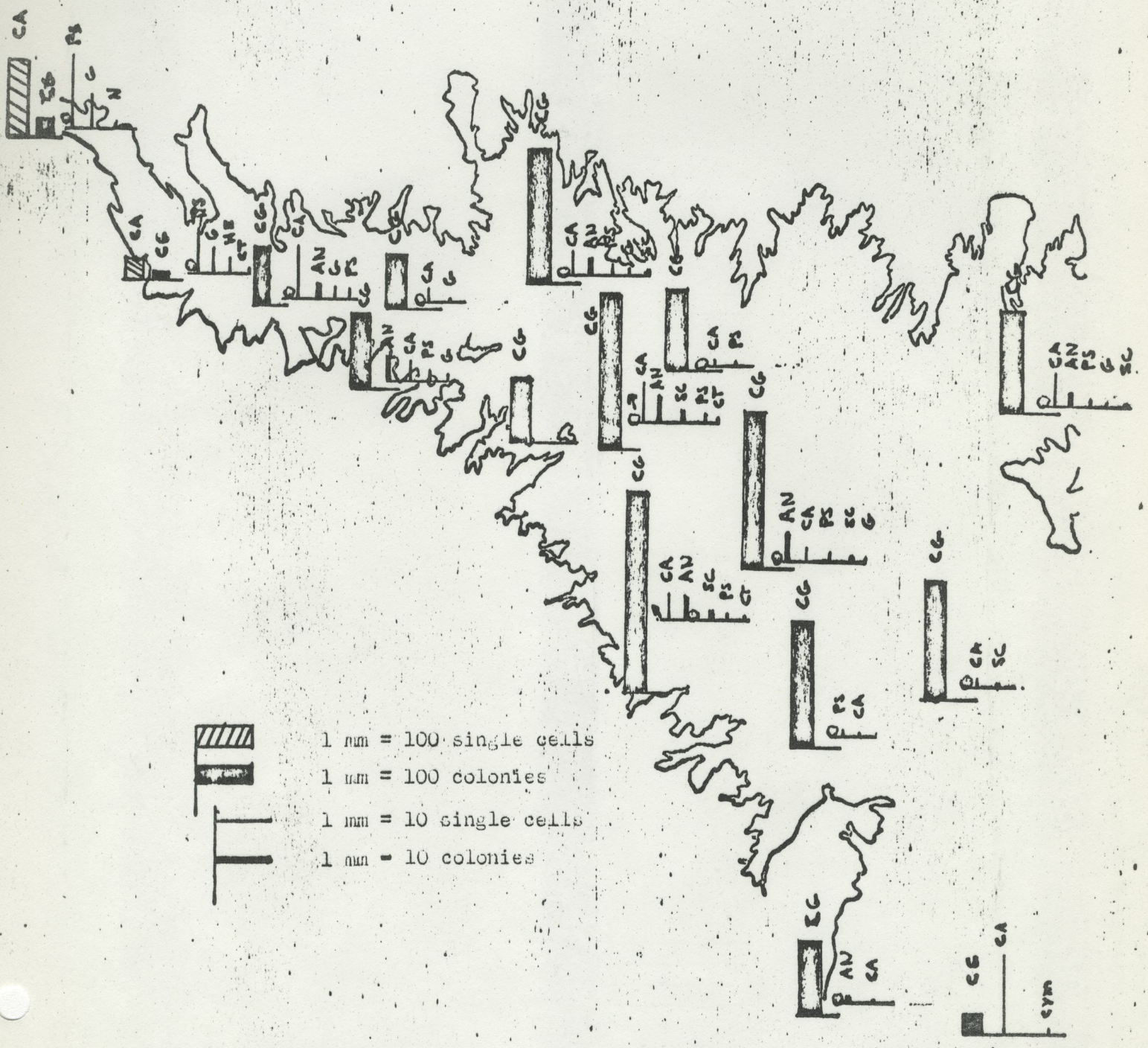


Fig. 30

Plankton in Las Vegas Bay 6/15/72

Colonial Green	CG	Epithemia	EP
Carteria	CA	Gomphonema	GO
Phacotus	PS		
Glenodinium	G		
Anacystis	AN		
Fragilaria	F		
Scenedesmus	SC		
Cymbella	Sym		
Ceratium	CT		
Synedra	SN		
Navicula	N		
Pleurosigma	PR		

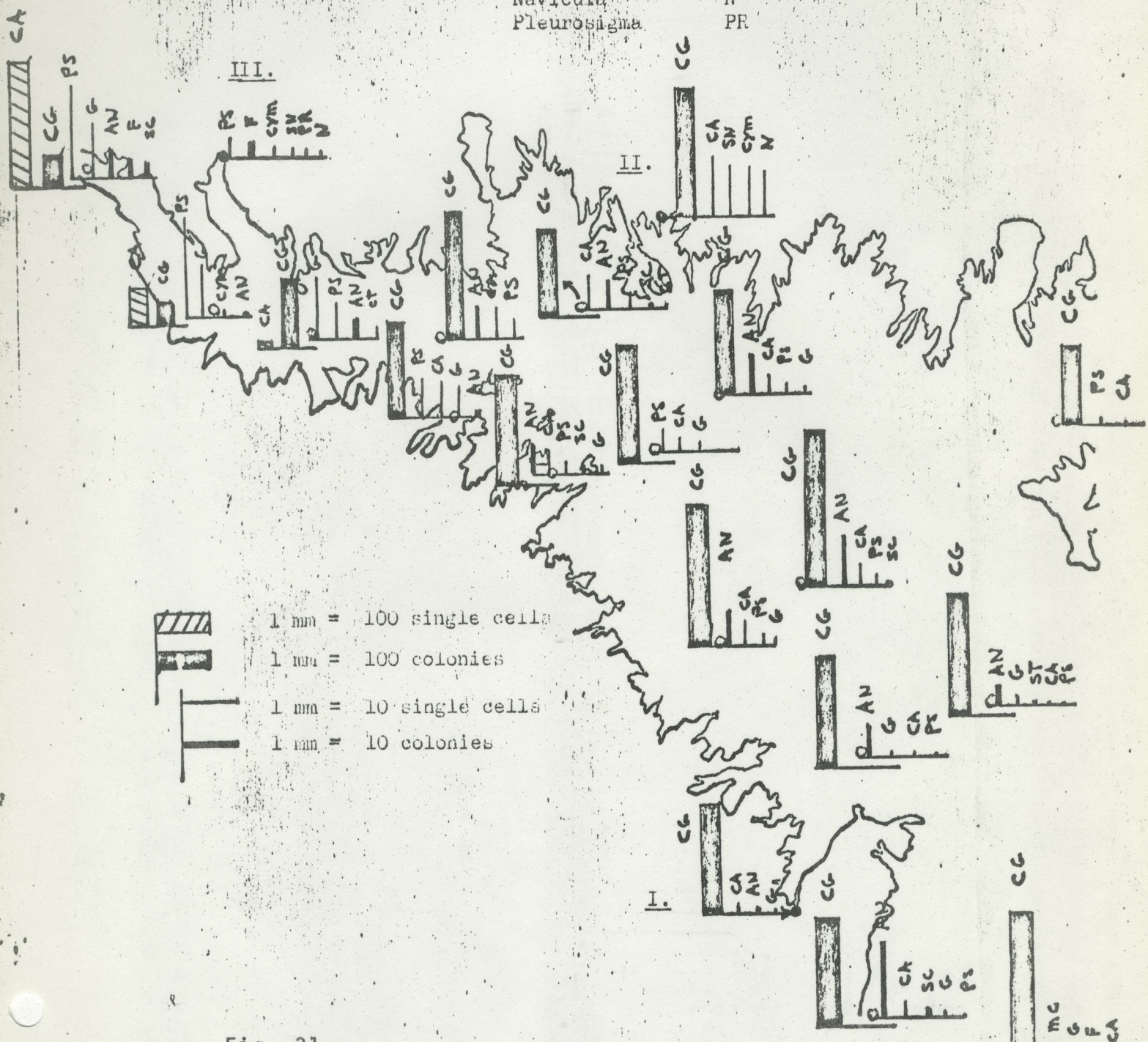


Fig. 31.
Plankton in Las Vegas Bay 6/19/72

Colonial Green	CG	Synedra	SN
Carteria	CA	Epithemia	EP
Chlamydomonas	CH	Nitzschia	NI
Pandorina	PD	Fragilaria	F
Glenodinium	G	Botryococcus	By
Scenedesmus	SC		
Spirulina	SA		
Phacotus	PC		
Anacystis	AN		
Cyclotella	C		
Navicula	N		
Ceratium	CT		
Stephanodiscus	ST		

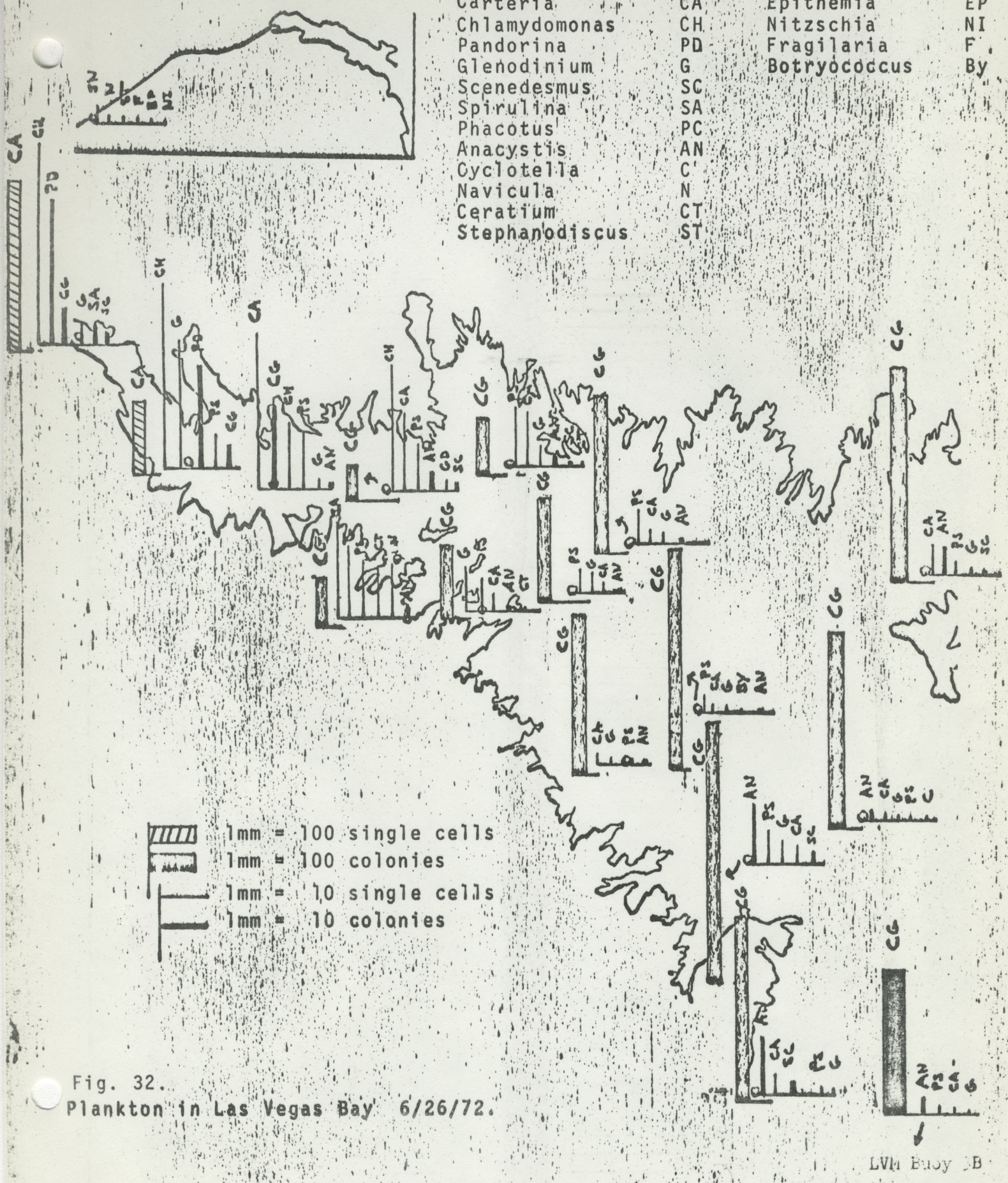


Fig. 32.
Plankton in Las Vegas Bay 6/26/72.

Colonial Green	CG	Synedra	SN
Carteria	CA	Epithemia	EP
Chlamydomonas	CH	Nitzschia	NI
Pandorina	PD	Fragilaria	F
Glenodinium	G	Botryococcus	By
Scenedesmus	SC		
Spirulina	SA		
Phacotus	PC		
Anacystis	AN		
Cyclotella	C		
Navicula	N		
Ceratium	CT		
Stephanodiscus	ST		

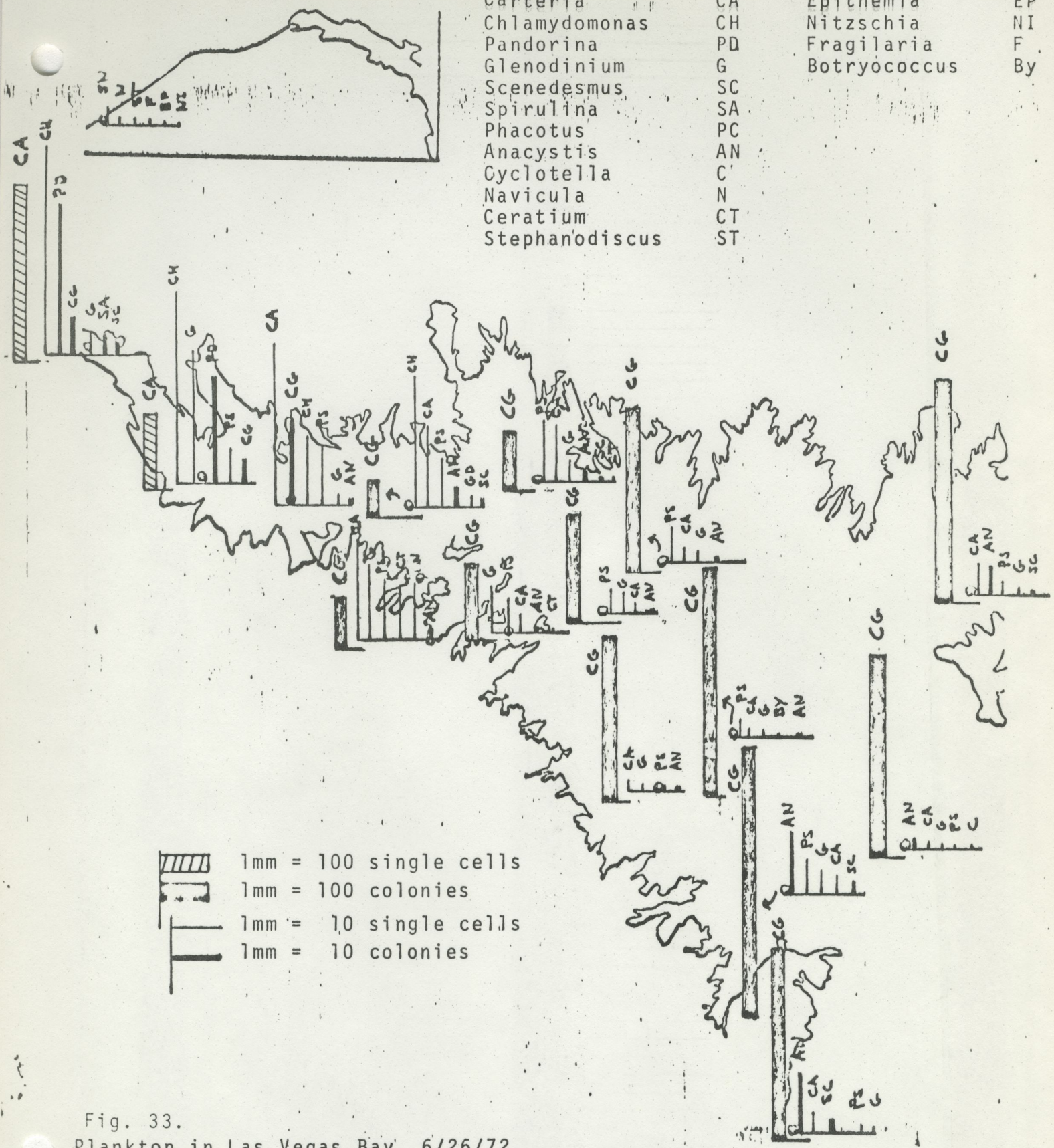


Fig. 33.
Plankton in Las Vegas Bay 6/26/72.

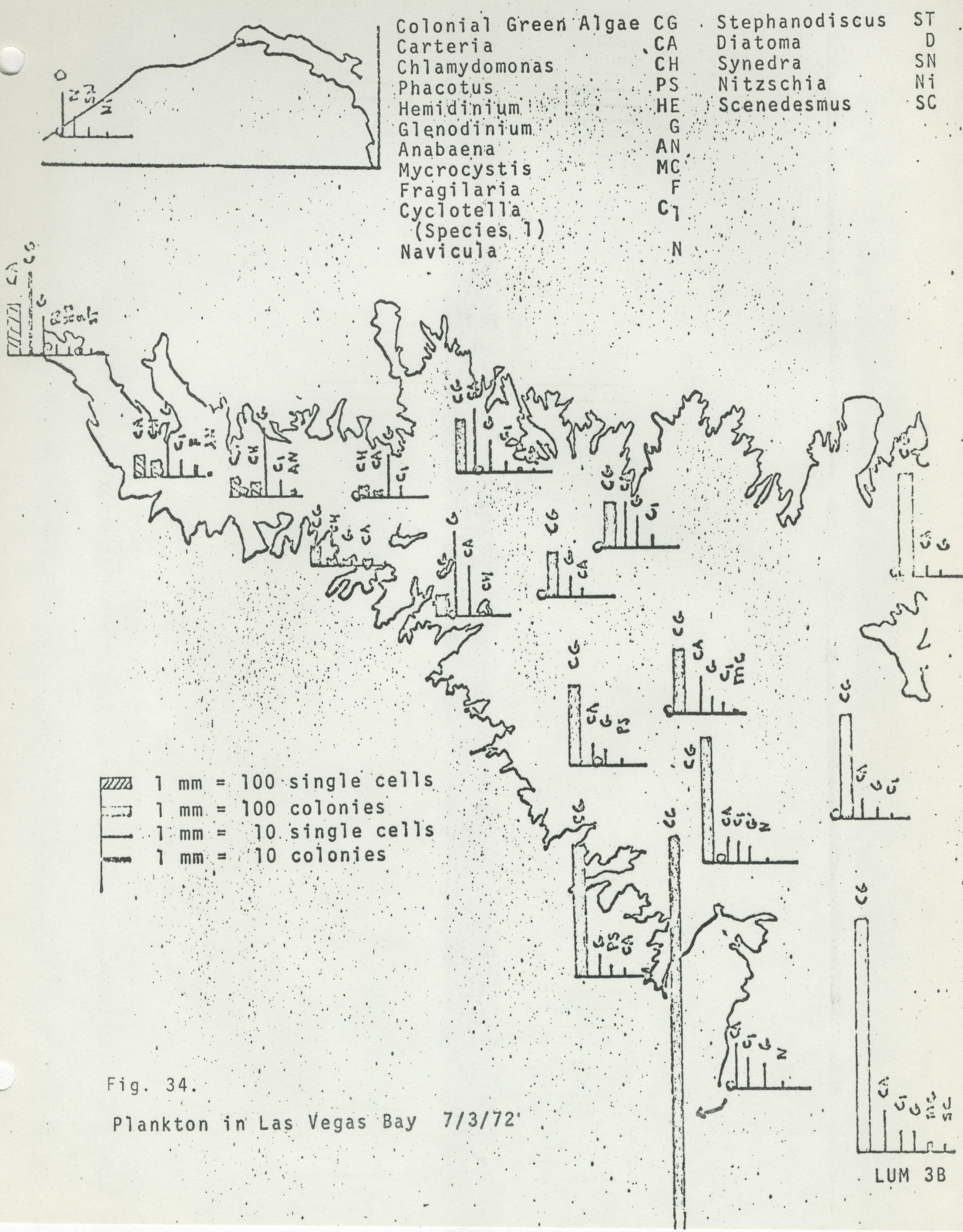


Fig. 34.

Plankton in Las Vegas Bay 7/3/72

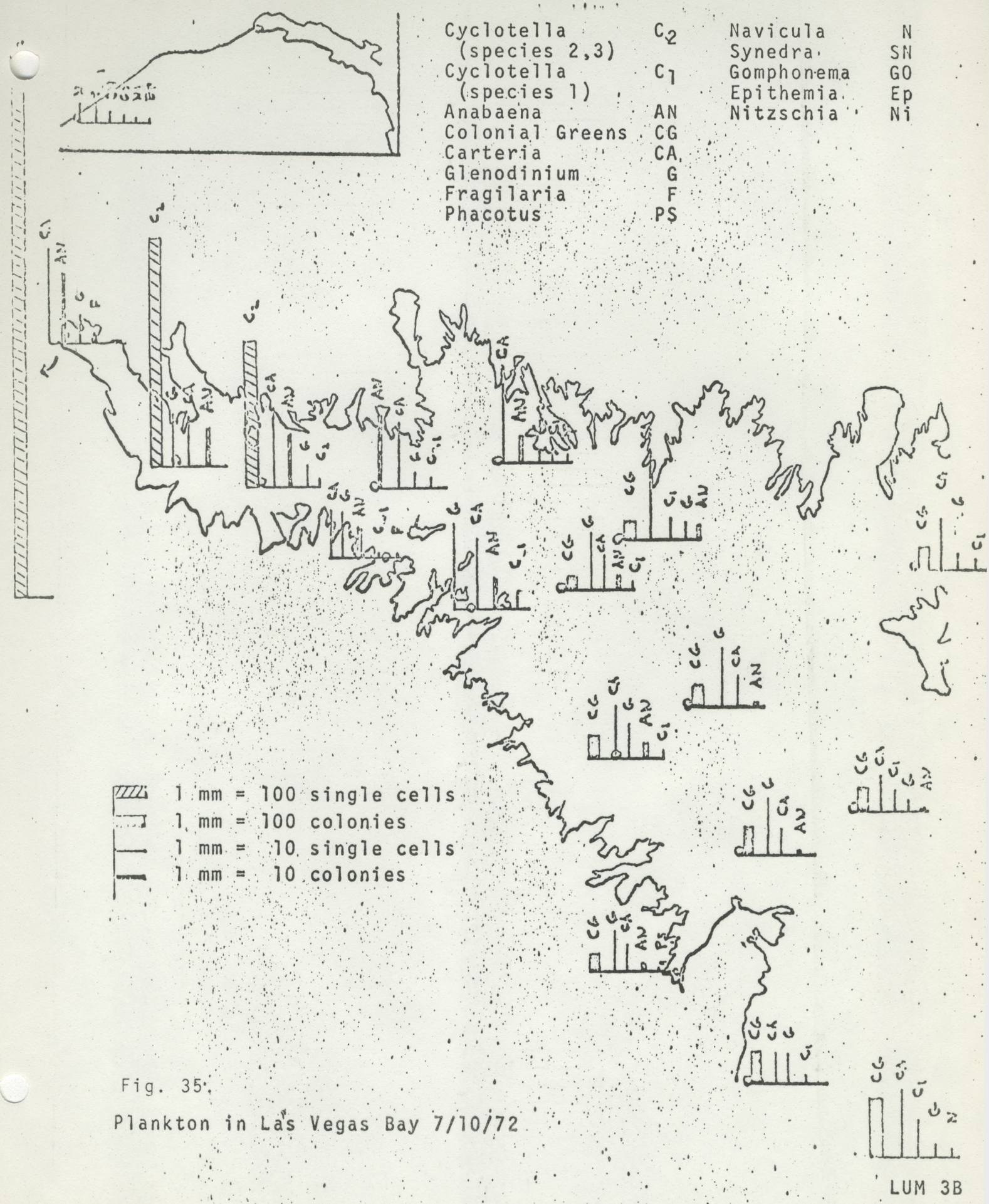


Fig. 35.

Plankton in Las Vegas Bay 7/10/72

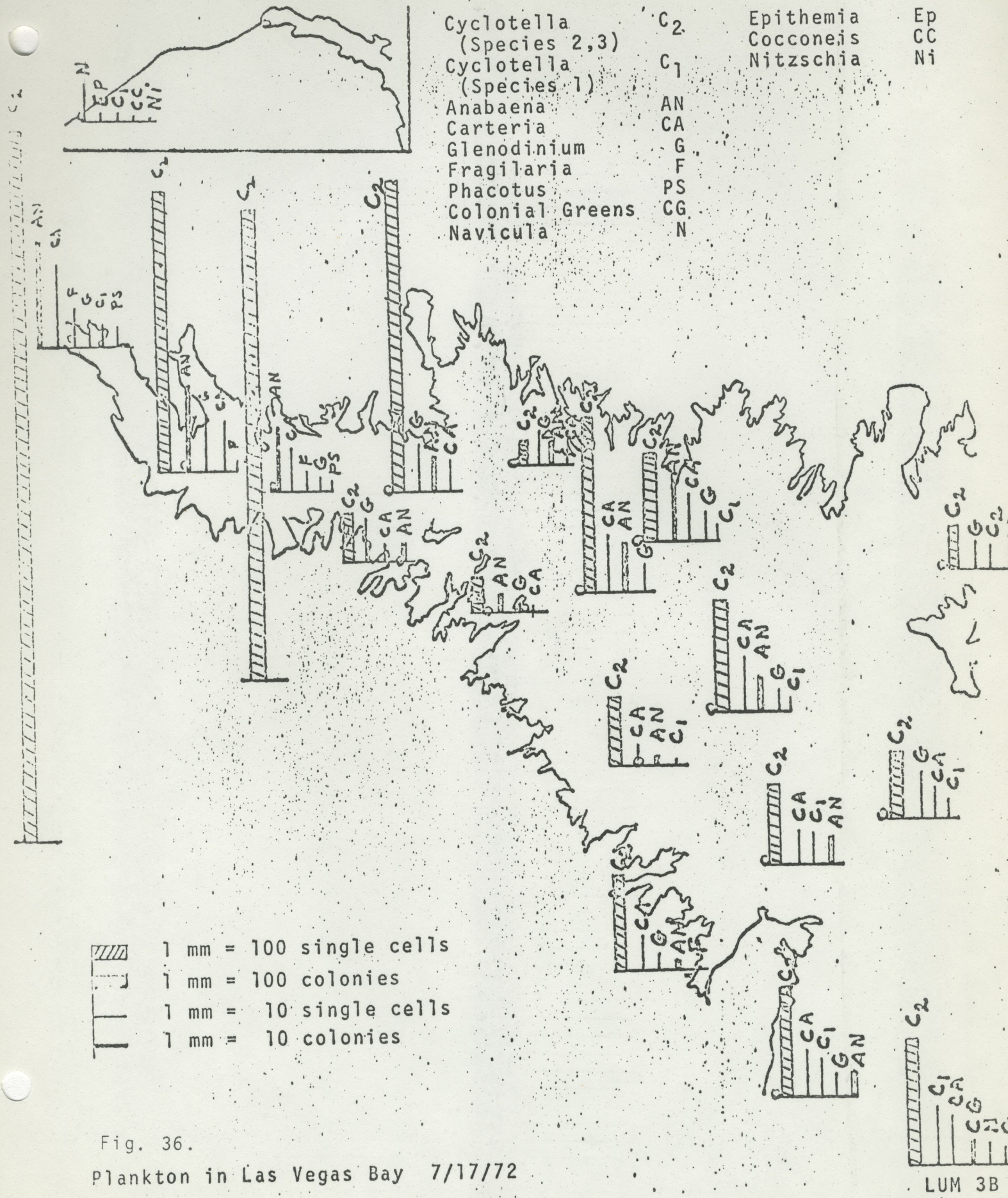


Fig. 36.

Plankton in Las Vegas Bay 7/17/72

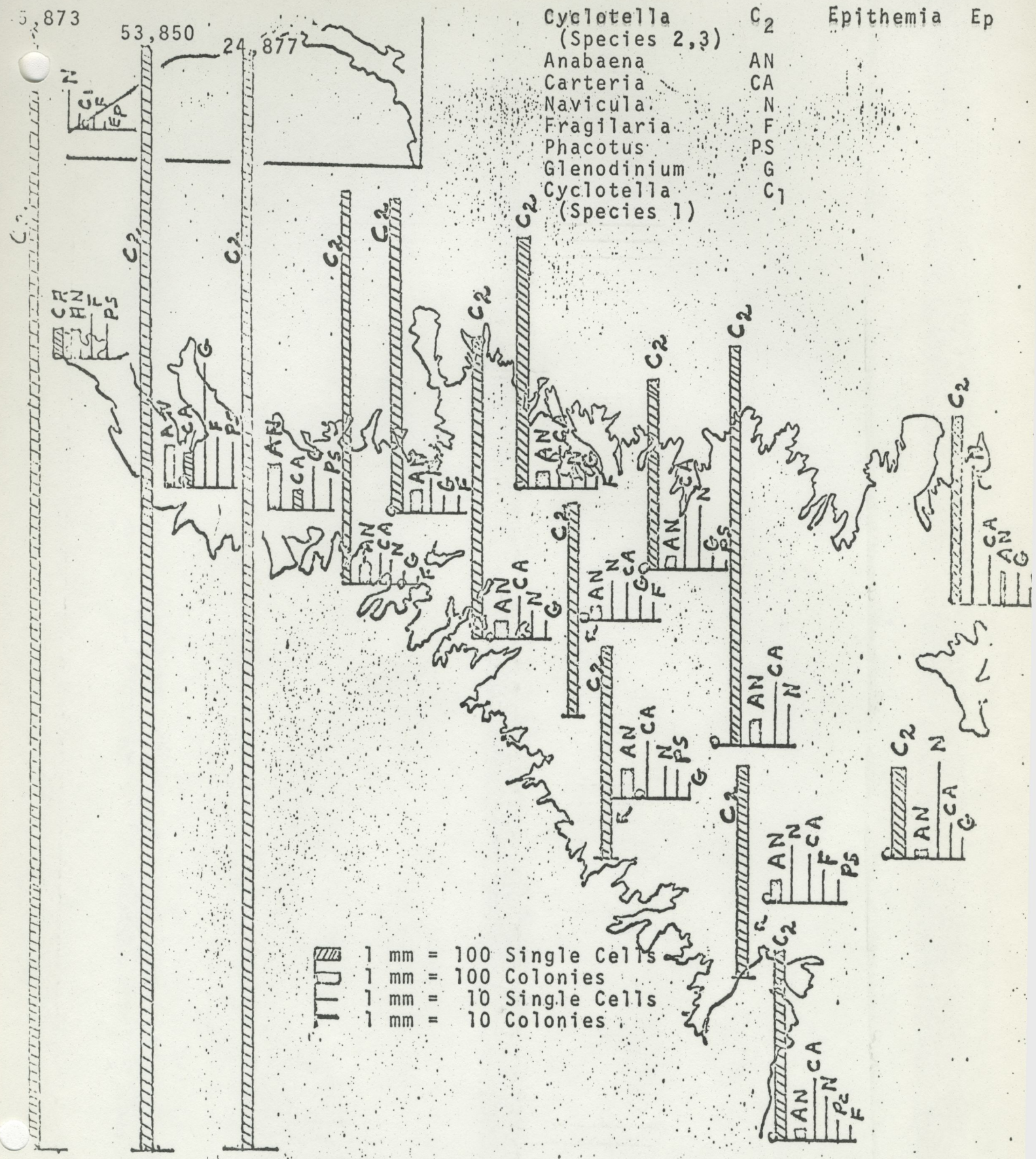


Fig. 37.

Plankton in Las Vegas Bay 7/24/72

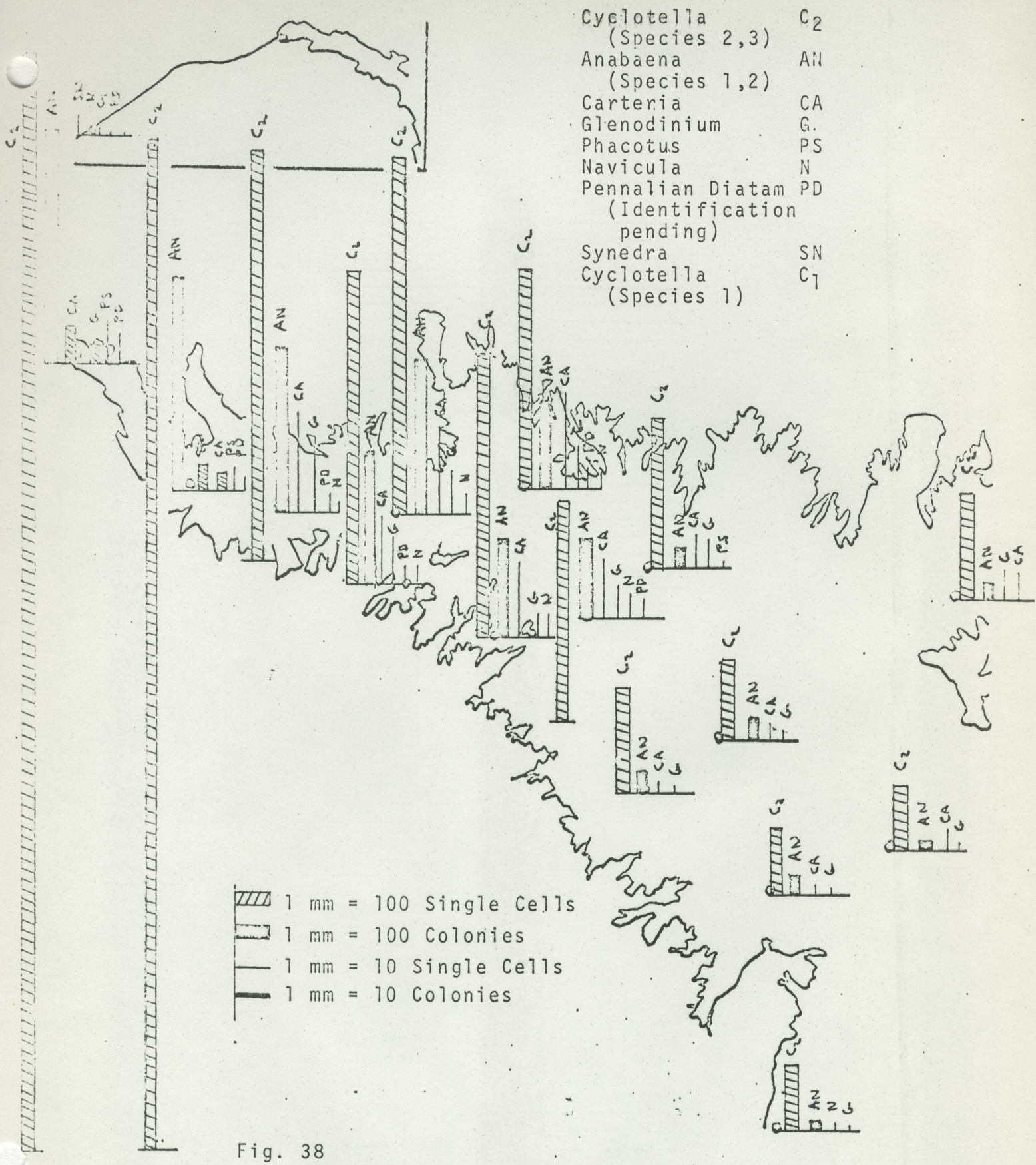
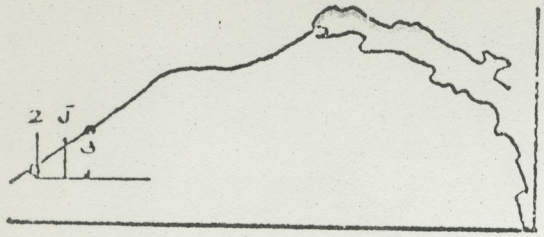


Fig. 38

Plankton in Las Vegas Bay 31 July 1972



Cyclotella (Species 2,3)	C_2
Cyclotella (Species 1)	C_1
Anabaena	AN
Carteria	CA
Navicula	N
Glenodinium	G
Phacotus	PS
Pennaliun Diatam (Identification pending)	PD

1 mm = 100 Single Cells
1 mm = 100 Colonies
1 mm = 10 Single Cells
1 mm = 10 Colonies

Fig. 39.

Plankton in Las Vegas Bay 14 August 1972

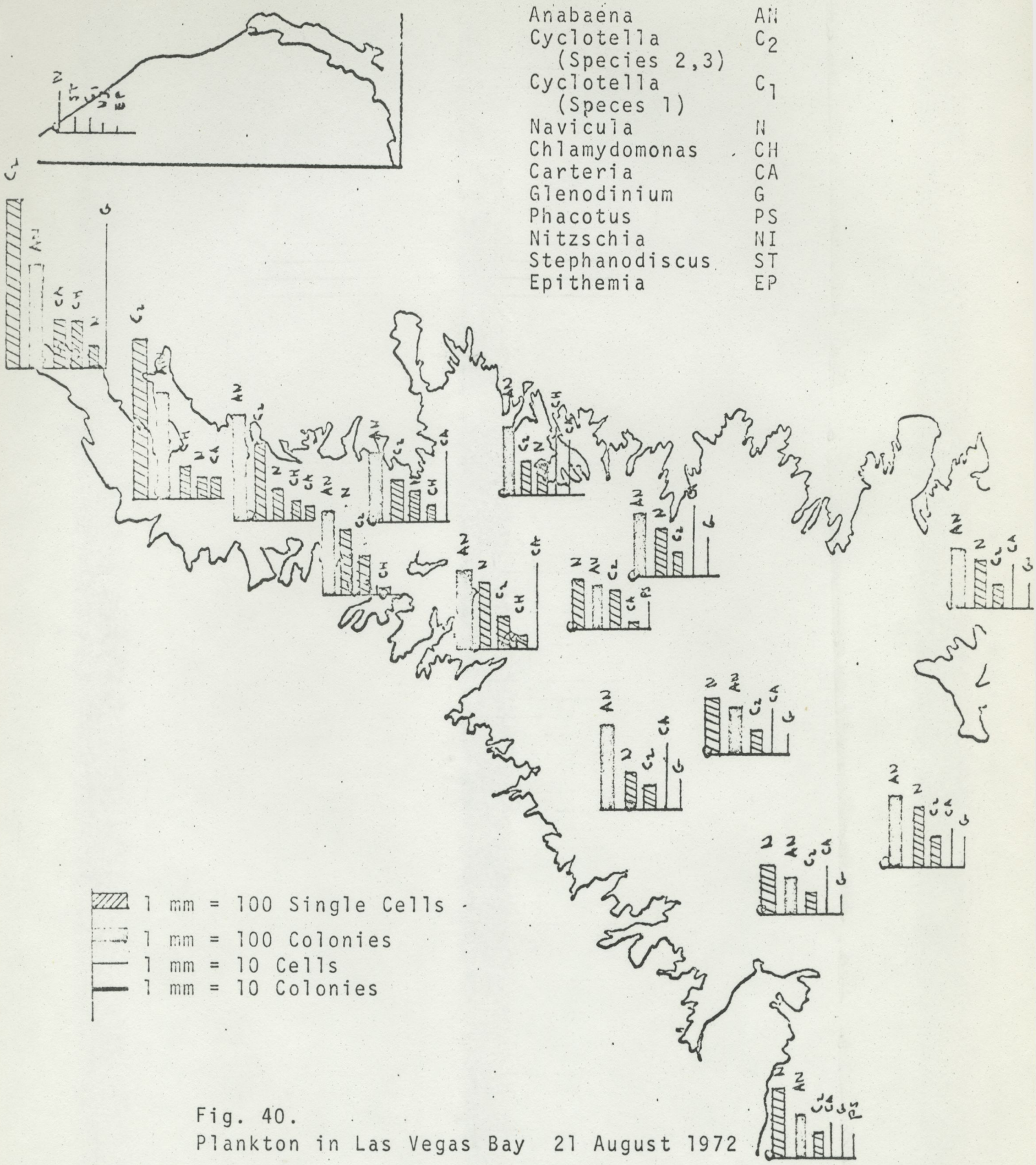


Fig. 40.
Plankton in Las Vegas Bay 21 August 1972

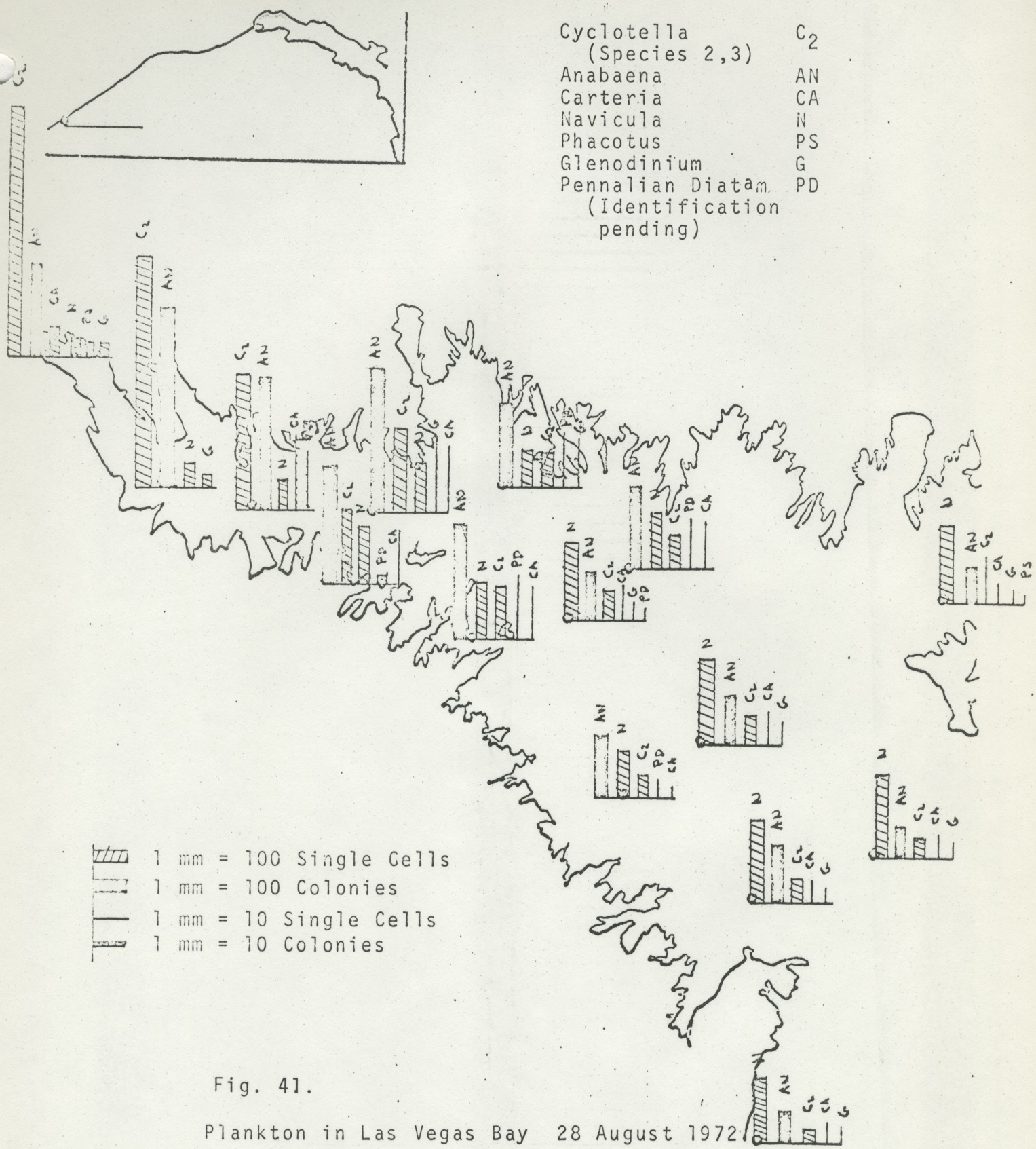


Fig. 41.

Plankton in Las Vegas Bay 28 August 1972

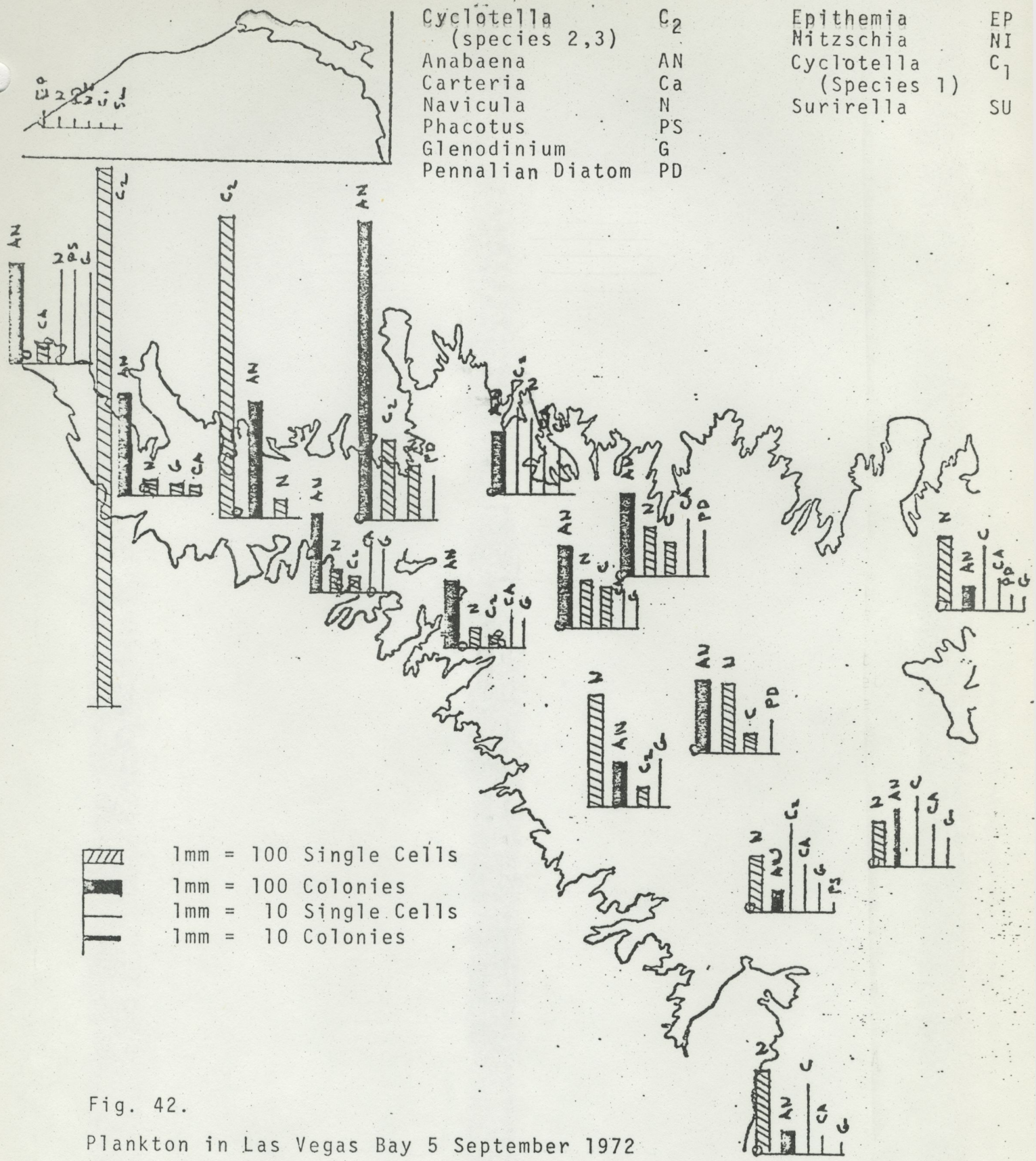


Fig. 42.

Plankton in Las Vegas Bay 5 September 1972

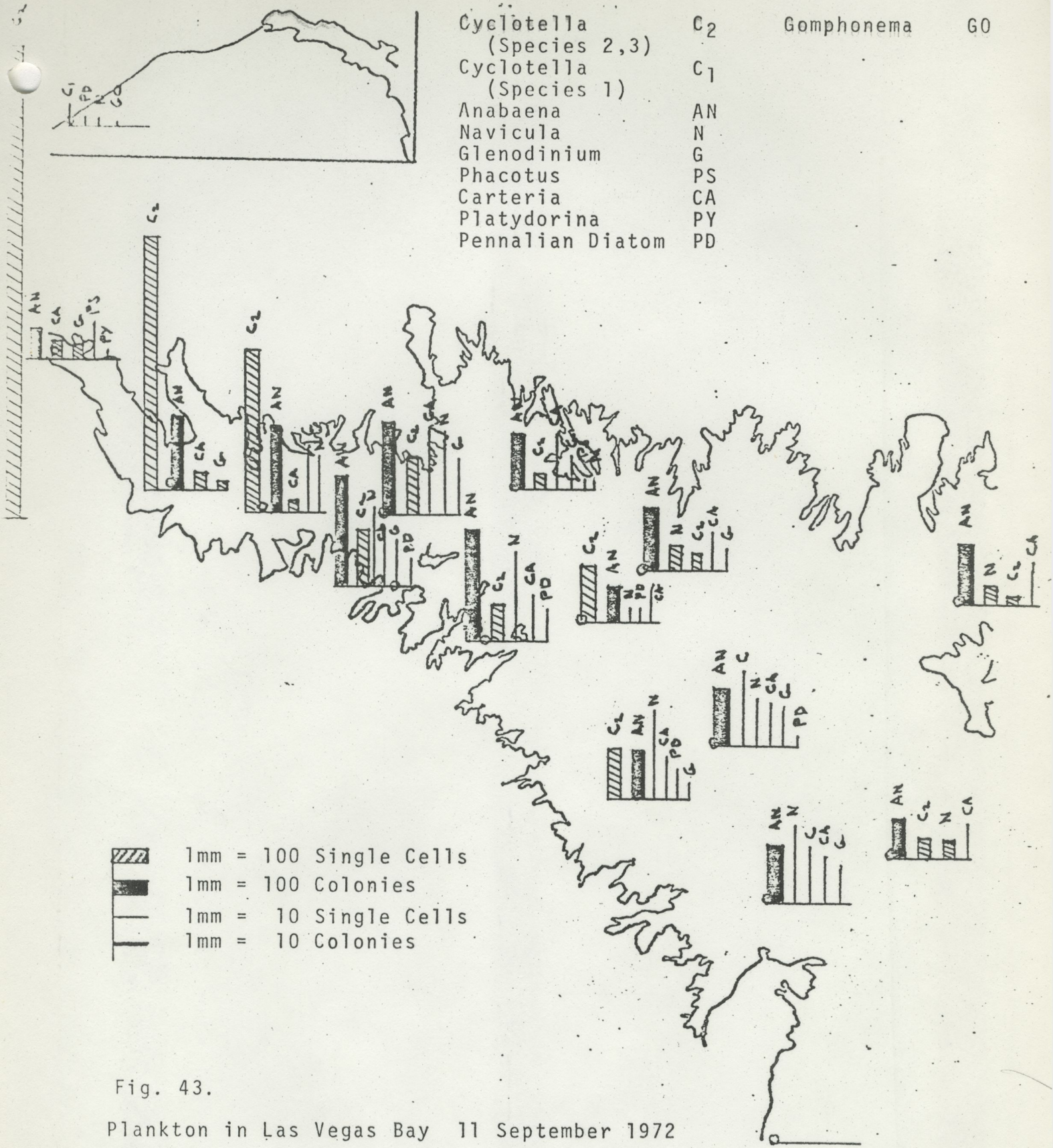
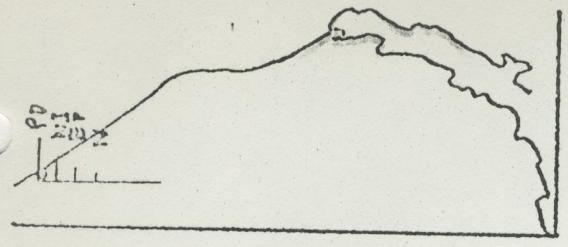


Fig. 43.

Plankton in Las Vegas Bay 11 September 1972



Cyclotella (Species 2,3)	C_2	Nitzschia	NI
Anabaena	AN	Epithemia	EP
Glenodinium	G		
Phacotus	PS		
Navicula	N		
Carteria	CA		
Pennalian Diatom	PD		

1mm = 100 Single Cells
1mm = 100 Colonies
1mm = 10 Single Cells
1mm = 10 Colonies

Fig. 44.

Plankton in Las Vegas Bay 18 September 1972

TABLE 30.

TEMPORAL AND SPATIAL DISTRIBUTION OF PLANKTON GENERA IN SURFACE SAMPLES TAKEN FROM LAS VEGAS BAY SAMPLING STATIONS

Classification	12/17/71	12/26/71	1/3/72	1/10/72	1/17/72	1/24/72	1/31/72	2/7/72	2/14/72	2/22/72	2/28/72	3/6/72	3/13/72	3/20/72	3/28/72	4/3/72	4/10/72	4/17/72	4/24/72	5/1/72	5/8/72	5/15/72	5/22/72	5/30/72	6/5/72	6/15/72	6/19/72	6/26/72	7/3/72	7/10/72	7/17/72	7/24/72	7/31/72	8/7/72	8/14/72	8/21/72	8/28/72	9/5/72	9/11/72	9/18/72	9/25/72	10/2/72	10/10/72	10/16/72	10/24/72	11/6/72
Chlorophyta																																														
Actinastrum		7,8,9,10	3,5,6	13,14,15											1-4,6, 8-15	2-15		3	2-4,6, 8			1,2,4,6, 8-14		3,7,9,11, 13,15	4,7,8			5																	
Ankistrodesmus																																														
Carteria	2-11,13-15	2-6	1-4,6,7, 9,12	1-12	1-15	2-15	1,3,4, 6-15	1-15	1-3,5-10, 12,13,15	1-15	1-14	1-14	1-10,12-15	1-15	1,2,4-8, 10-15	1-7,9-13, 15	1-7,9-13, 15	1-7,9,10, 12	1-14	1-7,9, 12	1-3,5-6, 9,10	1-10,12-15	1-12,14, 15	1-15	1-15	1-5,7-15	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-16	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-14	1-15
Chlamydomonas	2-11,13-15	2-6	1-9,12	1-14	1-15	2-15	1,3,4, 6-15 2,6	1-15	1-7,9-15 8	1-15	1-14 11,13	1-10,12-15	1-9,11, 13	1-9,15	1,2,4-6, 7-10	1,2,13	14	1,2,11	2	5,7,8	1-6	2,3 11	1-3,15	3,4	1-3			1-4	2-6							1-7										
Chlorella		7,8,9,10		13,15															8,11, 15,16																											
Closteridium						14																																								
Coelastrum																																														
Colonial Green Algae Palmellaceae, Oocystaceae																			16						1-4,6,8-11,14	1,5,10-12 1-15	1,3,4,6, 8,9,13,14 1-15	4,5,11 1-15	3 1,5-15	1,10,15 8-15	2,4,8 15	14,15				9,10,15							10			4
Cosmarium																																														
Crucigena												6,12	11	3,15		1					4	1-7,11, 12	1-5,8, 9	2-5,7,8, 11,12,14	1-4,6,8-12,14,15	1,4,5,7, 9-12	1-7,9-12, 15	1-8,11, 14,15	1,5,6, 15	5		10,12				13,15	4						6			8
Dictysphaerium																					1,5,9, 12												5,6,7,8													6
Hyalotheca												7,11	5	10,12	1,3,4, 12	1-4	1,2	2,3,7	1-4,7			1,3,7	5,9,13										12				2								6	
Legerheimia																				1,2,4	1-3	2	2-4,8	1,2	2,9,10, 16	2	1,2	1	1	2,11	2																
Micrasterias	2-11,13, 14	2-12,14, 15	2,3,5,7, 8,9,12	4,5-10, 12-15 1,5,10	1,3,4,5,6, 8-10,13-15		8,9																																							
Oocystis						11,12				11,13,14	8,14				2,3,6	1-5,11	5,7,8, 14	3,10,11 13,14	1,2,7,9, 11,14	1,2,4,5, 8,9,11,15	1-15	1-15	1,2,4-13	1,3,5-15	1-15				4	3-6	1-3,5,8-11,13 1,4-7,13	1,2,4-8, 10-15 2,10	1-3,5-8, 11,12,14,15 1,4,6,9-10,12 1-5,11-13,15	1,2,12, 15 1,14	1,3,4,5, 7-10,14,15 1,9	1-3,6,9-11, 13-15 2-6,9-12	1,2,4,8,10, 11,13-15 1,4,8,11, 13	1,3,8,9, 12 1-15	2,3	2,6,10-13 1,3,7,9-14	10 1-4,6-15 1-13,15	1,6,7,10, 13 4,5,8-13,15 1-15	1,5,8,10-12,15 1,2,4,6-8 1-16	1,6,8,13, 14 1,2,6,7, 13 1-15	1,7,9,10, 12-15 2,9 1,2,4-15	2,5-8, 10-13 1,3,6,9 1-11,13, 14 1,9,11	1-7,9-13 1-4,7-9, 11,12 3-7,14,15
Pandorina		2,3	1,3,5,9, 12	5					5															1-4,8,11-14	1-12,14 15	1-13	1-15	1-3,5,6, 12,13 1-15	1-6,8,10, 12,14 1,14	2,3,8,10, 11,13,15 5,7,15	2,7,10,12	6,7,9, 10,11	1-5,11-13,15													
Phacotus														1	1,3-6,9, 13 3	1-4,6-14	2-15 8	1-16	1-15	1-15	1-15 8,11-13	1-15 11	1-15	2-12, 14, 15				6													4,5,8,12		2,5,15	1,9,11	5,7,14
Planktosphaerium					3,8	12	7		15 4,11,14			11	1-3,5-8, 14,15	1,3,10, 15	1,2,4, 5,8,15	11	8,11	3,8,10	13	7,8	1,4,8,10-14	1,3,4,9-12 3	1	1,7,8,11, 12	1-4,6,10-12-15	2-15	1-9,11-15	1-5,7, 8,11-15	1-5,10,11, 14,15	1-4,6-10, 12-15	2,4,5,8, 15	2,5,6,7,8, 12,13,15	1-3,5,7, 14		1,2,6	1-10,12-14	1-4,6-12, 14,15	1,3-5,9-13	1,3,6,8, 9,14	1,4,5,7, 9-14	1,4-7	1-3,5-13, 15		1-4,11-14	1,2,4,6, 10,13,15	2,4-11,13, 14	1-5,8,9, 11-13,15
Platymonas																																														
Protoderma																																														
Scenedesmus	2-10,13-15	2-6	1,2,4-7	1-15	1-15	1-15	1-4,6-15	2-15	2-15	1-15	1-3,6,7, 9,10,12	1-9,12, 14																																	
Schroederia																																														
Tetradesmus			6																																											
Tetraedron		8		2,3-9, 13-15	2,3,4,8-11,13,14	1-8,10,11, 13,15	3,4,6-8, 11-15	3,4,6-11, 13	3,4,9, 15	3,6,8, 12	1	9,11 7	6,8,13	10,12,14, 15	15 1,3,4,13	14 10,14	11	1,2,4, 7,11	3 10	2		9	6,10		2			5				2 1-3	15 2	3,5,8	1,3,14	1,5,6, 11,12	1,2,5-8, 11,13		1-6,11,12	1-3,6,7, 9-12,14	1-3,8,9, 11,13,14	1,3,5, 8,13	2,5,6,10	1,6	1-3,5		

Classification	12/17/72	12/26/71	1/3/72	1/10/72	1/17/72	1/24/72	1/31/72	2/7/72	2/14/72	2/22/72	2/28/72	3/6/72	3/13/72	3/20/72	3/28/72	4/3/72	4/10/72	4/17/72	4/24/72	5/1/72	5/8/72
Pyrrophyta																					
Ceratium						1					14					4	1,11,14		1-4,7,8, 12-14	3,4,8,9, 12,13,15	1-15
Glenodinium		3,4,5,6	1-9,12		1-15	1-14	1,3-9,11-15	1-6,8-14	2-6,8,11, 13,15	1-15	1-15	1-15	1-15	1-15	1-15	1,2,4-15	1-3,6,9, 11-13,15	1-10,12, 14,16	1,2,4-7,9, 10,12,13,15	1,6,7,9-15	1
Gonyaulax																					
Gymnodinium	8	2																			
Hemidinium																1-3	1-7,9, 10	1-3,11	1-5	1,2	1-3
Peridinium	1,6-11, 13-15	2,7-11, 13,14,15	1-9,12	1-13	1-15	2-13,15	1-4,6-10,14	1-15	1,3-15	3-12,14	3	15				1-4					
Cyanophyta																					
Anabaena	2-7,14, 15	3,4,5	3,4,9	3,4,7, 9,10,11	14,15	8,14	7	15												9	
Coelosphaerium																					
Gleocystis																					
Merismopedia																					
Microcystis																					
Oscillatoria	2-11,13-15	2-7,9	3,4,7,8, 12,16	1-13	2-15	2-15	3,4,6-15	2,4,7-15	2-5,7-15	4,7-15	6,9,11,12	1			2-4	7	2,5	4	4,6,7,9, 10,13	3,4,6,8,9, 11,12,16	5-12,14, 15
Raphidiopsis			6																		
Spirulina							3									5	8,9		4,5,7	6	
Stichosiphon																					13
												6									
Cryptophyceae																					
Chilomonas															1,2,5,8		2,3		8	1	1
Euglenophyta																					
Euglena																					
Astasia							4													7	

5/15/72	5/22/72	5/30/72	6/5/72	6/15/72	6/19/72	6/26/72	7/3/72	7/10/72	7/17/72	7/24/72	7/31/72	8/7/72	8/14/72	8/21/72	8/28/72	9/5/72	9/11/72	9/18/72	9/25/72	10/2/72	10/10/72	10/16/72	10/24/72	11/6/72
1-6,8-13, 15	1-15	1,2,4,5, 8-10,13-15	1-15	1-3,5-15	1-15	4,8,11-15	1-9,12,14	5,8,12,14	14	5,6,9,10, 11,12				11,13				4					1-4,10	1,8,5,11
1,3,5-7, 9-12	1-11,13, 15	1,4-7,9-13		1-15	1-9,11-15	1-3,5,7,-15	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-14	1-15	1-15	1-15	1-15	1-15	1-14	1-15
		2,3	1-6,9-11, 14			4																		
1	2,8	1,2,4,8, 12	2,11	2	2,5,8	3,6	1		1	14														
				11	7	8,12	1-12,14	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-15	1-14	1-15
												5,9,15		8										
					12,15	1		5,8,10	2		2	10		11		4,5,6	1,11			1,5,8	2,4,11, 14	1,12,13, 14	6	1,5,8
		3,8,9, 12		1-3,5,7, 8,10-15	1-15	1-15	1,3-8,11, 13,15	2,5,6,10, 12,13,14	1,2,10	11,12,13, 14,15	1,6	6							2,8	1,2,8,15	1,2,7,8, 14	1,5,7,11, 12	2,7,8,10	2,8,12
1,2,5, 12,16	1-8,10, 12,16	1,8,11		5,8,13	1,4,5,7, 9	1-12	1,2,5,6, 10	8,14	1,3,4,8			6				1-3,10	1	6		5	6	6	9	4
		3,10		12	6,12	1,5,7,10	2,3,11																	5,6
							4,5,7,9																	
					1	1	2,5,8,11											2	1,4	1,2,9				1

Classification	12/17/71	1/26/71	1/3/72	1/10/72	1/17/72	1/24/72	1/31/72	2/7/72	2/14/72	2/22/72	2/28/72	3/6/72	3/13/72	3/20/72	3/28/72	4/3/72	4/10/72	4/17/72	4/24/72	5/1/72	5/8/72	5/15/72
Chrysophyta diatoms																						
Amphiporora						2,7																
Asterionella				6	6,10	4	6,7								11	11	2-5,7,9, 11,14	1-16	2-16	1-16	3-15	8
Chrysamoeba																						
Cocconeis									16						1,3	11	8		1,8,13, 16	2-4,8 13,16	1,2,6,8	2
Cyclotella	2-11,13-15	2-15	1-9,12, 16	1-15,16	1-16	1-15	1-4,6-16	1-15	1-7,9-13, 15,16	1-16	1,2,5-7, 9,10,12-16	1-9,15,16	1,2,3,6, 9,16	1,4-10,13, 14,16	2-9,11,14, 16	1,3-5,7,9, 10,16	1,2,6,7, 12,16	2,3,5,7-9,11,14,16	1,2,4,10 11,1-16	1-5,7,13, 14,16	1-3,5-10, 12,14-16	1-6,8-12, 14,16
Cymbella	3,4,7,9, 11	2,3,4,7, 10	1-8,12, 16	2,3,7,9-12,16	1-3,5-7, 10-14,16	1-14,16	1,2,4,5,6, 8,10-13,15	1-9,12,13	1-11,13, 14	1-15	1-14	1-14,16	1,3,5-9, 11-14	1,5,7-10, 12-15	2-6,8-12	1-4,7-12, 14	1-12	1-4,7,8, 10,12-14	1-10,12, 15	2-4,9, 12,13	1,2,4,6-9, 12,14,15	2-12,14
Denticula				16																		
Diatoma							1,5,9	1,6														
Epithemia						7,16	5,16	1,16	16	16	16	16	15,16		2,3,16	16	8,16	16	13,16		2	8,16
Fragillaria	2-4,6	3,4,10, 11,12	1,2,4,6, 8,9,16	1-15,16	1,3,4,5,7-11 15,16	1-3,5,7,8, 11-13,16	1,3-8,11, 13-16	1,8,14, 15,16	1,7,8,12, 14-16	1,2,5,12, 14,16	1-4,7,9,11, 13,16	1-6,12,16	1-5,10, 14,16	1,2,6, 13-16	1-7,16	1,3-5,8,10, 11,14,16	1,2,4,7, 8,14	1-4,8,10, 14,15	1-3,13-16	1-5,7-9, 11,16	1-16	1-16
Gomophonema			4	1,2,4,7,11, 13-16	1,3,6,9,10, 12,14,16	1-6,8-10, 12-14,16	1-4,7,9, 10,12-16	1,5,14, 15,16	7,11,16	1-8,12-15	1,3,6	1,2,5,7, 12,14,16	3,11	1	8	1,2,15	1,7	1,2	2,3,7			
Gyrosigma	9,10	3,8	3,16	14																		
Melosira				8	1	1,5,7	1,2,4,8	1	1	1,2	1	1,2	1	1,5	1				1	1,2	2,3,11	
Navicula	2,5,6,7, 8,11,13-15	2-7,10-14	1-4,8,9, 12,16	1-14,16	1-16	2-16	1-9,11-16	1-14,16	4-7,9-16	2-4,6-12, 14-16	1,2,4,5,7-10,12-14	1-4,6-9, 11,12,14-16	1,2,4,5, 11-14,16	1,9,14, 16	1-5,7, 10,16	1-4,7, 10,16	1-5,9,10, 13,16	1,3-5,7,9, 14,16	1-4,6,8, 10,14,16	1,2,6,7, 9,11,14,16	1-5,9,10, 12,15,16	1-6,8,11, 14,16
Nitzschia				16		1,16	4,5,16	1,13,16	16	16		16	16	16							16	
Pleurosigma		11,14	1	5	2	5,16	5,12									11	8	1,16		1,2	2,6	16
Rhoicosphenia			4,5,9, 12,16																			1
Rhopalodia				16	16	16	5,11	1,16	16	16	4,13,14		1		3							
Synedra	2-11,14, 15	2,3,4,6,7, 8,10	1-9,12,16	1-15	1-15	1,2,3,5, 6	1,2,3, 5-16	1-3,6-10, 12-16	1,3,5-10, 12-14,16	1,4,6,8-10,12-15	1,3,4,6-8, 10,11,13	1-9,11-14,16	1,5,7,9, 11,13,16	1,2,11	1-4,7,16	1,2,7,10, 14,16	1,2,4,8, 16	2,7,16	1-4,8, 13,16	1-4,6,16	1,2,5,8, 10,16	
Surirella	11		2,3	4,16													14,16			1,2	2	
						16	3,5															
Stephanodiscus	2-11,13-15	2-15	1-9,12	1-15	1-15	1-15	1-15	1-15	1-15	5,7-9,11, 12,13,15,16	4,8-11	1-3,5,6, 9-14,16		1	1	6,8,11, 14	3,4,8,14	4,7,13, 15		5,6	10	
Other																						
Botrycoccus										13		5				9,11,15	4,8	11,13,15	8,9,11, 12,14	3,4,7-11, 13-15	2,3,6,7, 10-14	2,3,10-15
Dinobryon																						
Mallomonas	2,3,5,6, 7,9,11	2,4	1,9,12	7	2,10,11	2				7,11,12,14	3-5,7,8, 10,14	1,3,4,6,7 9,10-14	1-4,7,8, 10-15	1,12,13			4,8	1-3	1-3		1,2	
Rhizochrysis																						

5/22/72	5/30/72	6/5/72	6/15/72	6/19/72	6/26/72	7/3/72	7/10/72	7/17/72	7/24/72	7/31/72	8/7/72	8/14/72	8/21/72	8/28/72	9/5/72	9/11/72	9/18/72	9/25/72	10/2/72	10/10/72	10/16/72	10/24/72	11/6/72
															16			16					
	10,13			1,11	7			11											8			12	
				6	15		12																
2,3,6, 14,16	1,2	9,10,16			11,16	16	4,12,15	5,16	2				9	1	1	16		5	6,12,16		7	3	
1-13,15, 16	1-3,5-7,9-11,15,16	11,16	3,6,16	6,7,12, 13,15,16	1,2,4,5,7, 9,11,14	2-5,7-16	1-4,6-16	1-7,9-16	1-16	1-16	1-15	1-16	1-16	1-15	1-16	1-14,16	1-16	1-16	1-16	1-15	1-16	1-14,16	1-16
1-7,9,10, 12	1-5,7,8,10,12,13,16	1-3,5-12, 14,15	1-3,5,11	1-5,7,8, 11	1-7,9-12	1-5,9, 11,12	1,3-8,10-12,15,16	1-3,5-10, 12,14	1,2,15, 16	1,2,4,7	1,3,7,9, 10,12	7,9,10		1,2,6	1,7,8,9	2-6,11, 12,16	1,8	2,4,5, 13,15	1,5,7, 12	1,7,8	1,2,5, 10	1,6-8	1,2,4, 14,16
						1,16	16																
6,16	16	1,16	16	1,16	1,16	1,16	16	2,16	16			10	1,16		16	16	16	16	16	16	16	16	16
1-16	1-15	1-15	1-5,7,8, 10,12,15	1-9,14	1-5,7-11, 13,14,16	1-10,14, 15	1-15	1-16	1-16	1-16	1-15	1-15	1-16	1-15	1-16	1-14,16	1-16	1-16	1-16	1-16	1-16	1-14,16	
	16	7,16	3,7,8,16	1,15	1,16	7,11	16		1,16			16	1	12,13		2,16	10	16	9	4		16	
1-3,5,10	1,8				3,9	1	1			1													
1-5,8-11, 16	1-4,6,7,9-11,13-16	1-3,5,7,9, 10,12,13,15,16	1-3,7,8, 10-12,16	1,3,4,6,7, 8,11,12,15,16	1,2,4,5,7, 8,10-13,16	1-5,7,9-11, 13,15,16	1-7,9-14, 16	1-16	1-15	1-8,11, 14-16	1-15	1-16	1-15	1-15	1-16	1-14,16	1-16	1-16	1-16	1-16	1-16	1-14,16	1-13,16
16		16			16	16	16	16	16	16			16		16		16		16	16	16	16	16
8,9,16	1,2,9,10			9	3,9						7		16				16	2,16	16	16			16
							16				5		16	6	16			5,7,8, 16	16	16	1,16	3,4,	16
1-8,10-12, 14-16 2,3	1,2,4,5,8, 9,14-16	1-3,6,9, 16	1	3,12,16	1-5,8,11, 12,15	1,6,8,10, 12,14-16	2-4	1-4,6,7, 11,13	1-5,7,8, 9,11,15	1,7,16	3,10	1	1	1,7,11, 14	16	8,10,14	1,6,11, 16 16	16	6,10,13 16 16	16	8,10,15, 16 16	2,7,16	2,6,7,16
9,14	8,11,12, 14-16	1,5,7,12	2,14	9,14	2,3,6,8, 10,12,16	1,6	3,11,16	1	6				16		3,16	8			2,8,13	8,13,16	1,7,9,12, 13,14-16	8,16	
1,2,4-6, 10-12,15	2-5,9,12, 14,15	2-11,14, 15	1-7,9-15	1-15	3,4,6, 8-15	3,5,6,8, 10-15	5,8,10, 11,13-15	5,10			10												
14	1,3,5-7, 9,11	1,3,6,7,9, 10, 12-15	2,3,6,8, 10,13,14	1,3,4,6, 9,11 2,3	2,11	1,13							1						1,4,6-8, 14	1,2,6,14	1,2,6, 14,15	1	1,7

Classification	12/17/71	1/26/71	1/3/72	1/10/72	1/17/72	1/24/72	1/31/72	2/7/72	2/14/72	2/22/72	2/28/72	3/6/72	3/13/72	3/20/72	3/28/72	4/3/72	4/10/72	4/17/72	4/24/72	5/1/72	5/8/72	5/15/72
Zooplankton																						
Amoeba						14				8,13			7			1	1,2	2				
Difflugia				5	1-5,7-15	1-7,9-14	1,3,4,6,8, 9,12,14,15	1	6,14	4,11	8,15	1	12									
Ciliophora										4,8,13, 14	4,8,12		1,4,7		1,3			1,2	1			
Astylozoon																			1-3			
Coleps birtus															1							
Vorticella											8											
Gastrotricha																						
Chaetonotus																						
Rotifera unidentified	2-9,11, 13-15	2	2				11	2,3,11					15	11								
Cephalodella									2,3,5,14									1,2	1-3			
Filinia																						
Keratella						1	8	3		1,4,6,10, 12,14	6,9	3,5,7, 12,13	1,3,10-15	4,12,14	1				6	2,3	2,5	2,4,8, 9,11
Philodina																						
Bosmina					1,8,11	1	8,12		2,6			6	1	5,8			1					
Daphnia																	2					
Nauplius stage of Copepoda																						
Cyclops																			1,2,10	8	1	1
Diaptomus									1,5		4		1,4,6,11	2			3,8		3,7			

5/22/72	5/30/72	6/5/72	6/15/72	6/19/72	6/26/72	7/3/72	7/10/72	7/17/72	7/24/72	7/31/72
				1	1					
			2	1,3		2		1,3,8, 9,11	1,2,5,13	1,4,5,8
				1	2,3,6,8	1,6		2		
								3,4		
		1,3,7,12, 13,15	12	4,5,7-9,12	6,10		2			
	11									
				6	4-7,9,10, 12,13	2,7-11	1-4,7, 9,12	1-3,5-9, 11-15	1-15	1-3,5-8, 10,14
		1	12	1	2,3,6	1,6,10		14		
	5	1		1,3,12		2-5,11	6	1,3,9, 15	1,2	2
2-6	1,2,3	12,4,6, 9,11	2	4,9	5,6,8,9, 11,12,14	6,8		6,10		8
								1,2		
		3	5							
			6							
4										

8/7/72	8/14/72	8/21/72	8/28/72	9/5/72	9/11/72	9/18/72	9/25/72	10/2/72	10/10/72	10/16/72	10/24/72	11/6/72
	1,2,4,7	1	1	1,3,10	1,3,9,10	2,3,4	1,6				2,8	1,2,8,11
3,4,6	1-3,5-9, 11-13,15	1-7,9, 11,13	1,3-5,7-9, 11,13,14	1,2,4,8, 14	1-5,7-9,11-14	1-4,6,7, 9-11	1,2,4-6, 8-14	1-6,8,10, 12-15	1,4,5, 8,11	2,5,10, 12,13	1-8,10-13	1,2,3,6,12
	14	14	6,15									
	6			6	7		8,13	13		5,6,11	5,7,11	7,12,14
7					1,2,10, 11,13,14	1,3,5,6	1,5,9-11,14	8,10,15	2,6,7, 8,13	7,9,10	1,9,11,14	2,3

Nutrient Enrichment

Tables 31 and 32 summarize results of nutrient enrichment tests. For each date indicated each element was assigned a number from one to eight, depending on their relative stimulation of growth. One indicates maximum stimulation and eight minimum stimulation of growth during a particular test period. The numbers totaled for the entire year represent a relative index of the importance of each element in limiting algal growth at the head of Las Vegas Bay. Lower numbers indicate relatively greater limitations on algal growth while higher numbers suggest that the element is present in sufficient quantities that it is not imposing limitations to growth of the organisms in the flasks.

The summary indicates that algal growth in water from both surface and bottom at Station 1 is most severely limited by nitrate, minor elements and phosphorus, and that other nutrients are variable but in general probably are plentiful enough to support growth of more algae than presently grows in Las Vegas Bay throughout the year. It is interesting to note that phosphate varies from imposing the most severe limitation on growth in mid-March to imposing the least severe limitation in early February and again in early March. In general, phosphate ranks behind nitrate and Provasoli's 8 minor elements as important in imposing limitations on algal growth in the inner portion of Las Vegas Bay. The essential nutrients

Table 31. Relative effectiveness of the indicated element in stimulating algal growth. The numbers indicate the most (1) to the least (8) limiting element in surface waters of Station 1 on the dates given.

Date	NO_3	PO_4	SO_4	Ca	K	Mg	Fe	Minor Elements
Jan 17	1	5	6	4	8	6	3	2
Feb 7	3	8	2	5	1	7	6	3
Feb 22	1	4	7	3	5	2	8	5
Mar 6	2	8	7	6	5	4	3	1
Mar 20	2	1	4	7	6	3	7	4
Apr 3	3	4	7	2	8	5	6	1
Apr 17	1	4	6	3	4	6	8	2
May 1	1	3	2	7	3	8	3	3
May 15	1	2	4	8	4	4	4	3
May 30	1	4	7	6	7	2	4	3
Jun 14	1	6	6	4	6	3	4	2
Jul 5	1	6	3	3	6	8	3	2
Jul 17	1	3	4	8	5	7	5	2
Jul 31	1	2	7	6	8	5	4	3
Aug 14	1	7	7	3	5	5	4	2
Aug 28	1	5	7	6	2	4	4	2
Sep 11	1	6	6	3	5	3	8	2
Sep 25	1	2	2	2	2	2	2	2
Oct 10	1	3	8	6	2	4	6	5
Oct 24	1	5	3	4	2	8	5	5
Total	26	88	105	96	94	96	97	54

Table 32. Relative effectiveness of the indicated element in stimulating algal growth. The numbers indicate the most (1) to the least (8) limiting element in bottom waters of Station 1 on the dates given.

Date	NO_3	PO_4	SO_4	Ca	K	Mg	Fe	Minor Elements
Apr 15	1	4	6	3	4	6	8	2
May 1	1	3	3	2	8	3	3	3
May 15	1	2	2	2	2	2	2	2
May 30	1	4	6	3	7	5	8	2
Jul 5	2	1	8	7	6	3	4	5
Jul 19	1	2	8	5	5	5	4	3
Jul 31	1	2	7	6	7	4	5	3
Aug 14	1	8	3	3	7	6	3	2
Total	9	26	43	31	46	34	37	22

currently imposing limitations to growth of algae in Las Vegas Bay of Lake Mead are nitrate and Provasoli's 8 minor elements. Addition of these elements to waters of the bay would doubtless result in increased algal production. Addition of phosphorous would have a variable effect depending on time of year and nutrient balance of the waters. Addition of sulfate, calcium, potassium, magnesium or iron would generally have minimal effect on algal production. The conclusion by EPA (1971) that Las Vegas Bay is phosphorus-limited may still remain valid except in the head of Las Vegas Bay where the high phosphorus input apparently permits algal growth to proceed to the point of nitrogen limitation.

Pigment Analysis

Pigment concentrations of chlorophylls A, B, C, astacin and non-astacin carotenoids were measured using acetone extraction of samples filtered with a millipore filter. Estimates of pigment concentrations attributable to diatoms and to combined green and blue-green algae were made using formulae presented by Parsons and Strickland (1968) and developed into a computer program which Donna Portz, Arizona State University, kindly made available to us. Data on pigment concentrations are presented in the appendix and summarized in Figure 45 where mean pigment concentrations from stations in inner, middle and outer bays, respectively, are presented.

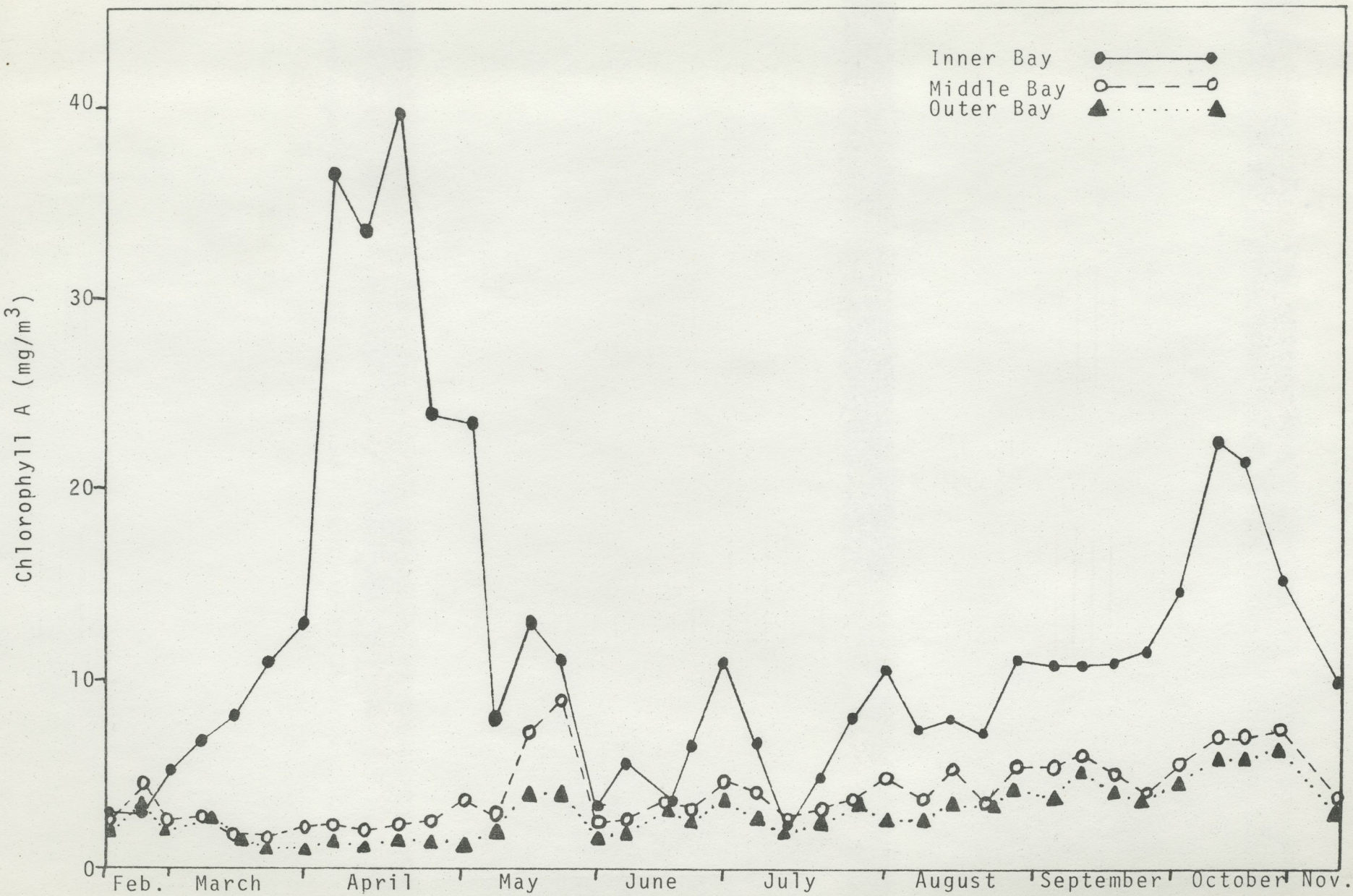


Fig. 45. Mean chlorophyll A concentrations (mg/m^3) in inner, middle and outer sections of Las Vegas Bay, Lake Mead.

Analysis of photosynthetic pigments provides a measure of the producer standing crop thereby reflecting the quantity of material present that is responsible for productivity.

Phaeophytin causes unreliability of data during periods of relatively extensive phytoplankton mortality. During periods when relatively few dead algae occur in the water, interfering phaeophytin is minimal and the chlorophyll estimates are quite useful measures of standing crop. We began measurements of chlorophylls and carotenoids on 14 February.

In general chlorophyll analysis (Fig. 45) shows highest biomass of algae occurring at the head of Las Vegas Bay during April, relatively variable quantities through the summer and a secondary maximum in October. Highest algal biomass in the middle and outer bay occurred in May and again in October. Fluctuations in biomass are much more pronounced in the inner bay than in other parts of Las Vegas Bay.

Phosphorus

Phosphorus cycling in Lake Mead has been of considerable concern by a variety of agencies. While this study was not primarily directed toward elucidation of phosphorus cycling, we have developed some suggestions that may be useful in consideration of the problem. Table 33 presents data on surface concentrations of total phosphorus for the center channel stations in Las Vegas Bay. Data for other stations are available

Table 33.

Total Phosphorous (mg/l) for Channel Stations

Date		Stations 16	1	2	3	4	8	11	14
May	1	4.76	.026	.016	.016	.023	.015	.014	.025
	8	6.03	.102	.050	.027	.016	.015	.016	.016
	15	4.24	.007	.007	.003	.007	.002	.002	.000
	22	3.47	.007	.007	.003	.003	.003	.003	.003
	30	4.60	.018	.016	.007	.007	.007	.003	.005
June	5	5.54	.046	.023	.007	.000	.003	.005	.003
	15	4.66	.028	.016	.010	.007	.007	.013	.013
	19	4.04	.039	.012	.011	.007	.007	.005	.005
	26	2.93	.046	.026	.003	.003	.003	.003	.003
July	3	5.87	.024	.020	.011	.007	.006	.007	.007
	10	5.87	.012	.020	.013	.013	.012	.024	.012
	17	3.02	.035	.035	.022	.020	.018	.020	.016
	24	3.88	.042	.023	.011	.014	.007	.007	.007
Aug	1	-	-	-	-	-	-	-	-
	7	-	.007	.007	.007	.006	.006	.007	.007
	14	3.85	.060	.037	.015	.007	.007	.007	.007
	22	-	.053	.046	.028	.011	.016	.012	.018
	27	-	-	-	-	-	-	-	-
Sept	4	4.12	.045	.048	.024	.019	.024	.013	.012
	11	3.48	.081	.042	.029	.020	.020	.017	.017
	18	3.28	-	.074	.029	.017	.014	.014	.011
	25	2.85	.049	.041	.024	.019	.021	.014	.014
Oct	2	3.72	.093	.043	.032	.016	.016	.016	.015
	10	3.69	.117	.076	.029	.018	.014	.010	.008
	16	5.07	.152	.045	.032	.018	.015	.011	.012

in the appendix and include some information on concentrations at other depths. In general concentrations are higher at the thermocline and near the bottom than they are at the surface of the lake. Also, concentrations decrease from the head to about Station 4 at both surface and bottom. Outward from Station 4 concentrations change relatively little and do not follow a consistent pattern. The dilution referred to previously is apparent and is extremely marked from North Shore road (Station 16) to Station 1. It can be seen, although certainly less evident and less consistent from Station 1 through Station 4.

Marshall and Orr (1961), Rigler (1961), and Pomeroy (1963) have shown that zooplankton are important in regeneration of phosphorus above the thermocline in the ocean. Rigler (1956) on the other hand showed that bacteria were much more important to cycling of phosphorus in freshwater habitats than were zooplankton. Kuenzler (1961) and Greer (1971) have shown molluscs to be very effective in removing or recycling phosphorus in a very short period of time. Increases in phosphorus content of the water have been previously noted by us to be associated with the thermocline and relatively higher bacterial and fish populations at that level in the lake. Also, work on nutrient enrichment has suggested that enough phosphorus is present in the lake water at the head of Las Vegas Bay to support more algal growth than occurs presently and at that location nitrogen and minor elements are probably the most important limiting

nutrients. Elsewhere in the lake phosphorus may be limiting.

Tentative suggestions relative to phosphorus, therefore, are as follows:

1. The quantities entering Lake Mead from Las Vegas Wash stimulate algal growth in the head of Las Vegas Bay.

2. Phosphorus is rapidly stripped from entering waters by hydroxyl-apatite formation, uptake by algae, filtration by clams, and dilution by the large volume of the lake. This is especially true during the period of no thermal stratification.

3. A major portion of the nutrients available to algae in Lake Mead, including Las Vegas Bay, are produced (or cycled) by the living organisms present in the lake. Shad in particular seem to be important in this regard and utilize detritus as an important food source.

4. If flow from Las Vegas Wash is cut off, algal populations in the inner bay area of Las Vegas Bay can be expected to decline rapidly to a level that may approximate those in the outer bay. Algal populations elsewhere in the lake will likely respond more slowly and less dramatically.

5. Nutrient regeneration from the bottom sediments is apparently minimal now and can be expected to remain so whether or not flow from the wash is interrupted.

Oxygen Depletion

Oxygen concentrations in the waters of Lake Mead have been referred to infrequently in the literature. Moffett

(1943) mentioned that sufficient oxygen occurred at all depths throughout the year to permit complete utilization of the reservoir by fish. Jonez and Summer (1954) noted that after six weeks of thermal stratification the reservoir contained in excess of 4 ppm of O_2 in the hypolimnion. Hoffman et. al. (1967, 1971) pointed out the existence of a reverse heterograde oxygen profile in Lake Mead and suggested that it may be related to decomposition of organic material in the thermocline or to the existence of a flat contour in Virgin and Boulder basins that may be considered somewhat shelf-like. Hoffman et. al. (1967) referred to a comment made by Hutchinson (1957) to the effect that the depth of an oxygen minimum may correspond to a shelf in the bottom contour, but then suggested that more probably factors associated with filling Lake Powell led to a general degradation of water quality in Lake Mead. This degradation was observed in part as a decline in quantities of dissolved oxygen. They also pointed out that proximate factors causing this oxygen depletion should be identified and measured. Everett (1972) mentioned the existence of the reverse heterograde oxygen profile and discussed oxygen relations in the lake from the viewpoint of hypolimnetic oxygen depletion. His data appear to be limited to the upper 50 m. It is apparent from Table 34 that that fact is probably responsible for his conclusion that hypolimnetic oxygen levels in Lake Mead during September are unsuitable for cold water species and for his implied assumption that nutrient regeneration occurs from the bottom muds.

Table 34. Vertical profiles of dissolved oxygen in ppm at various points in Lake Mead.

Location	Black Canyon	Station 14 Las Vegas Bay			Overton Arm near Echo Bay	Boulder Canyon	Virgin Basin		Temple Basin	Gregg Basin	
Date	23 Aug 72	23 Aug 72	25 Sept 72	16 Oct 72	14 Oct 72	31 Aug 72	31 Aug 72	14 Sept 72	14 Oct 72	14 Oct 72	Apr 64
Depth (m)											
0	8.1	8.9	8.9	8.6	8.5	9.0	8.5	9.4	9.0	10.4	9.6
5	8.1	8.9	8.2	8.4	8.3	8.4	8.9	8.5	8.7	10.2	
10	7.9	7.7	8.0	8.3	8.3	8.0	8.1	8.1	8.4	9.8	9.7
15	6.9	3.0	6.4	8.1	8.1	5.1	6.8	5.9	8.3	8.7	9.4
20	1.5	2.7	2.6	8.0	3.9	4.7	5.8	4.9	6.1	8.6	
25	1.3	1.7	1.8	2.2	3.4	4.7	5.7	4.4	6.6	8.3	
30	1.7	1.7	1.2	1.7	3.2	3.6	5.6	4.6	6.9	8.1	9.0
35	2.8	2.5	1.7	1.1	2.8	3.6	5.8	4.7	4.3	8.0	
40	3.6	3.6	2.2	1.5	3.0	4.6	6.1	5.1	4.4		
45	4.0	3.9	3.0	2.6	3.3	5.7	6.4	5.6	5.1		8.5
50	5.2	4.0	3.4	3.2	3.2	6.2	6.3	6.0	5.5		
55	5.8	4.3	3.7	3.6	3.6	6.5	7.1	6.5	5.9		
60	5.9	5.1	4.0	3.7	3.8	6.8	7.0	6.6	6.2		8.5
65	6.2	5.4	4.4	3.8	4.3	7.0	7.2	6.8	6.5		
70	6.3	5.4	4.7	4.1		7.1	7.1	7.0	6.7		
75	6.4	5.7	5.0	4.6		7.1	7.1	7.1	6.7		
80	6.6	5.9	5.2	4.8		7.1	6.8	7.1	6.8		
85	6.6	6.0	5.5	5.0		7.1	6.7	7.1	6.6		
90	6.6	6.1	5.7	5.2		7.1	6.5	7.1	6.6		

Boulder Basin				Las Vegas Bay near Station 11				Las Vegas Bay near Station 8					
Nov 65	Apr 66	Nov 66	Nov 68	Apr 64	Nov 65	Apr 66	Nov 66	Apr 64	Nov 65	Apr 66	Nov 66	Aug 68	Nov 68
7.7	9.6			9.7	7.7	9.8		9.6	8.0	11.7			
		7.8					7.9				8.0	8.2	7.7
	9.7			9.9		9.8		9.6		9.3			7.6
	9.0		7.4	9.1	7.6	8.7	7.8	9.7	7.7	8.7	7.7	5.2	7.6
2.5	0.3	7.5	7.3	8.7	7.6	8.2	7.7	8.9	8.0	7.8	7.7	1.9	7.7
2.0			2.0	8.7	2.3			8.7	0.02	7.5	0.05	3.8	2.0
3.1	7.7	4.3	4.2	8.4	1.8	7.3	3.2	8.7					
							3.8						
	6.8												

Our sampling in Las Vegas Bay and infrequently at other locations in the Lake has yielded considerable information on the existence of the negative heterograde oxygen profile and its relationships with other environmental parameters. Fig. 46 summarizes oxygen measurements taken at Station 14 from March to November 1972 at depths of 0, 30 and 90 meters. This clearly indicates that the reverse heterograde oxygen profile begins to develop in May, becomes most pronounced in July through October and is eliminated suddenly with disappearance of the thermocline in early November. Data from other stations in Las Vegas Bay follow this same pattern (see appendix).

Sampling at other localities in Lake Mead during August, September, and October reveal that oxygen depletion in the metalimnion occurs throughout most areas of the Lake but differs in severity. Table 34 presents illustrative data on vertical distribution of oxygen in various areas of the Lake during 1972 as well as comparable data available from earlier studies. In general Las Vegas Bay and Boulder Basin have the most pronounced metalimnetic oxygen depletion. The zone of depletion, however, is broader in Las Vegas Bay than in Boulder Basin. Overton Arm shows a broad zone of depletion similar to Las Vegas Bay but does not appear to reach quite as severe minima. Black Canyon shows a narrower zone of depletion, similar to, but more severe than measured in Boulder Canyon, Virgin Basin and Temple Basin. Gregg Basin did not show a negative heterograde oxygen profile when measured on 14 October 1972.

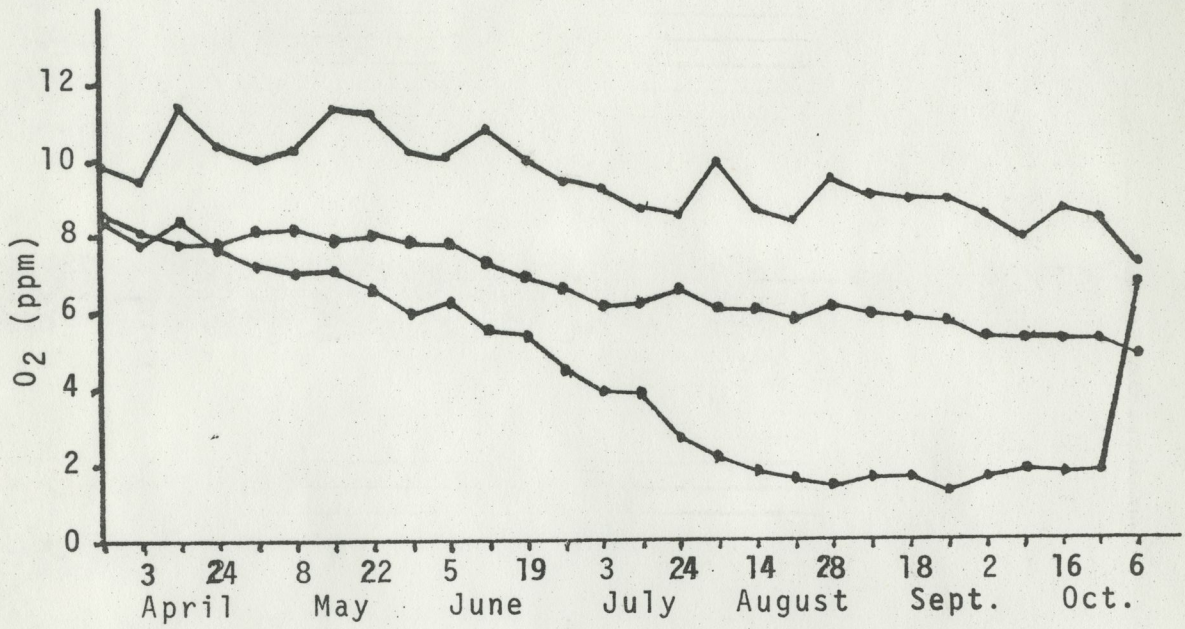


Fig. 46. O_2 conc. (ppm) at surface, 30 m and 90 m, at Station 14, Las Vegas Bay, Lake Mead, 1972.

Data developed by Hoffman et. al. (1967) and Hoffman et. al. (1971) and presented in part in Table 34 show that the negative heterograde oxygen profile was present in 1965, 1966, and 1968. Furthermore, the most severe depletion recorded at stations that are comparable to ours occurred in 1965 and 1966. We did record minima of 0.0 ppm O_2 occasionally at the bottom at Stations 3 and 5 in August and September. Minima of less than 1.0 ppm D.O. were not uncommon throughout Las Vegas Bay during the period July--November at depths of 20-40m. However, data at comparable times of year from our stations established near stations reported on by Hoffman et. al. (1967 and 1971) do not reach minima reported by them. For example, Hoffman's lowest reported D.O. measurement from near Station 8 was 0.02 and 0.05 ppm in November 1965 and November 1966 respectively. Our minimum D.O. measurement at Station 8 was 0.5 ppm during October 1972 (Table 34 and appendix).

Although earlier data are somewhat sketchy, it appears that metalimnetic oxygen depletion may have first developed in Lake Mead in 1965 and may have been as severe then as at any subsequent time. Additional examination of historical data may yield more information regarding this problem.

Relationships between the reverse heterograde oxygen profile and other parameters in Lake Mead have been examined. A thermocline may or may not be present in the lake as classically defined. However, the region of most rapid temperature decline (metalimnion), when it exists in Las Vegas Bay,

invariably has a zone of oxygen depletion associated with it. Fig. 47 presents representative data from Station 14. Complete data from all stations are presented in the appendix. The pattern shown in Fig. 47 generally holds for other stations that are sufficiently deep. The reduced temperatures per se, of course, do not cause oxygen depletion but probably produce density differences which slows the sinking rate of suspended particulate organic matter from above. The result is probably accumulation of debris in the metalimnion.

We reasoned that if accumulation of debris was occurring in the metalimnion, it was possible that bacterial action in breaking down the organic matter was the cause of oxygen depletion. Accordingly, on 10 and 24 July and 22 August we collected water samples in a vertical profile at Stations 4 and 14 for determination of numbers and kinds of bacteria. On 10 and 24 July "total viable bacteria" were cultured on a medium similar to that described by Taylor (1940) and coliforms were cultured on a violet red bile agar selective for lactose fermenting bacteria including Enterobacter, Escherichia coli and Aeromonas. The samples on 22 August for determination of "total viable bacteria" were cultured on tryptone-glucose-extract agar. Results of these determinations are presented in Tables 35-38 and summarized in Fig. 48.

At Station 4 on 10 July, maximum bacterial counts occurred at 15m and the biggest oxygen decrease was measured

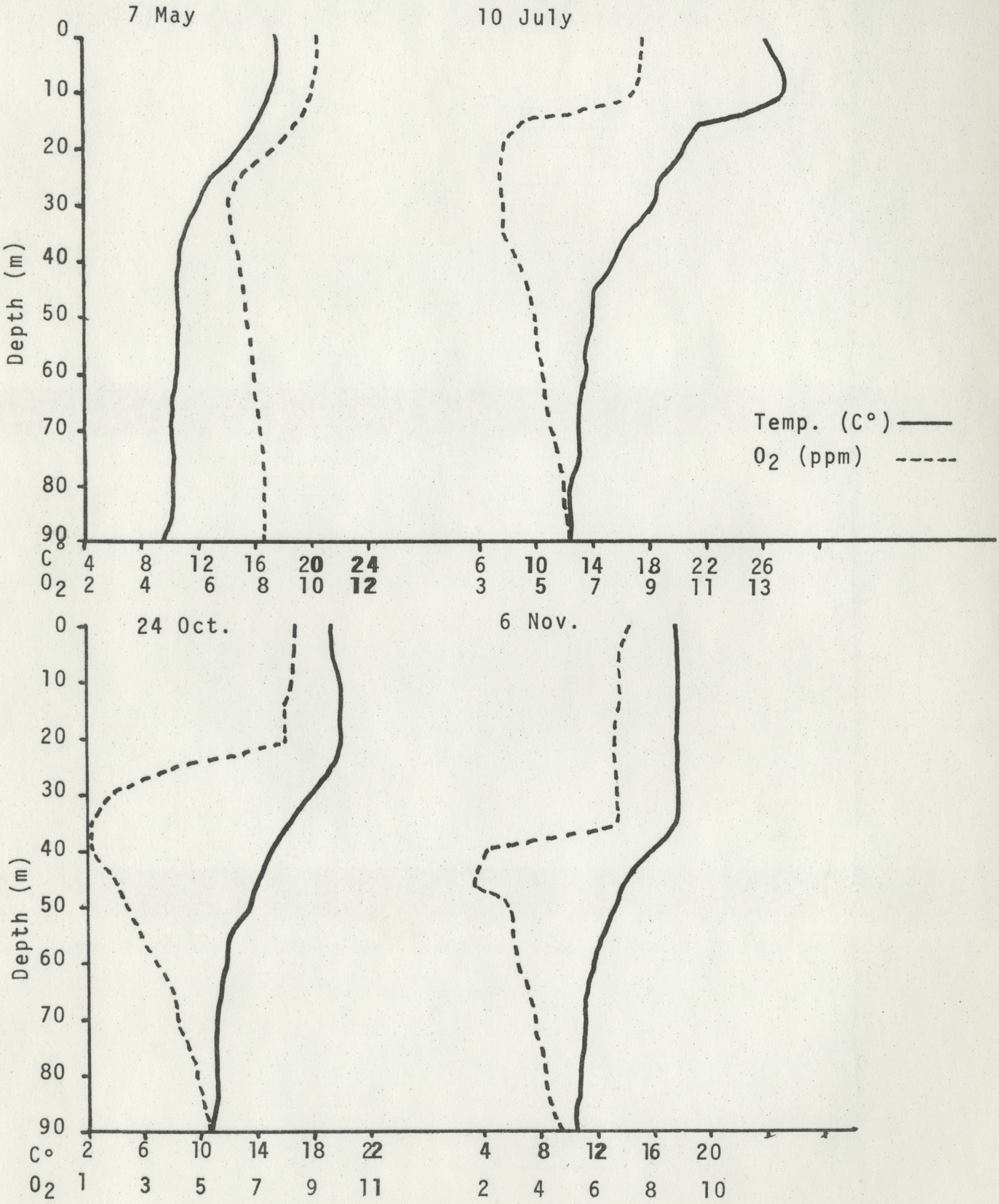


Fig. 47. Temperature and oxygen profiles at Station 14, Las Vegas Bay, Lake Mead, 1972.

Table 35. Total Viable Bacteria and Coliform Colonies (#/ml) for Station 4 in Las Vegas Bay of Lake Mead. July 10, 1972.

Depth in meters	Incubation Time		
	Total Bacteria		Coliforms
	2 days	10 days	
0	-	-	-
5	84 ± 19	3700 ± 300	0
10	114 ± 39	4200 ± 300	6 ± 4
15	141 ± 24	5900 ± 300	33 ± 1
20	129 ± 12	4500 ± 330	35 ± 1
30	84 ± 14	2300 ± 610	18 ± 2
44	534 ±120	2500 ± 530	50 ± 0

Table 36. Total Viable Bacteria and Coliforms Colonies (#/ml) for Station 4 in Las Vegas Bay of Lake Mead. July 24, 1972.

Depth in meters	Incubation Time		
	Total Bacteria		Coliforms
	2 days	10 days	
0	14 ± 3	209 ± 4	0
5	78 ± 5	480 ± 16	2 ± 5
10	37 ± 7	710 ±114	8 ± 2
15	34 ± 8	450 ± 62	15 ± 4
20	31 ± 5	530 ± 22	2 ± 1
30	40 ± 4	450 ± 36	2 ± 1
44	126 ± 5	500 ± 25	7 ± 4

Table 37. Total Viable Bacteria (#/ml) in Samples from Las Vegas Wash and Las Vegas Bay, 22 August 1972.

	Stations							
	16		1		4		14	
Depth, m	$\bar{X}$	σ*	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
0	11,400	920	96	13	29	5	14	3
3			280	34				
5					-	-	35	8
10					40	4	44	4
15					260	70	25	4
20					470	64	30	4
25					800	44	39	3
30					290	37	80	9
40							23	1
44					220	12		
50							56	4
60							35	2
70							47	5
80							10	3
90							83	17

*n-1 = 4

Incubation time - 10 days

Table 38. Coliform Bacteria (#/ml) in Samples from Las Vegas Wash and Las Vegas Bay, 22 August 1972.

	Stations							
	16		1		4		14	
Depth, m	$\bar{X}$*	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
0	440	46	14	6	5	2	0	-
3			52	2				
5					-	-	2	1.4
10					10	5	4	2
15					29	4	6	3
20					48	5	7	2
25					84	3	23	4
30					44	4	29	3
40							18	2
44					83	7		
50							2	1.6
60							19	5
70							29	3
80							0	-
90							45	3

*n-1 = 4

Incubation time - 2 days

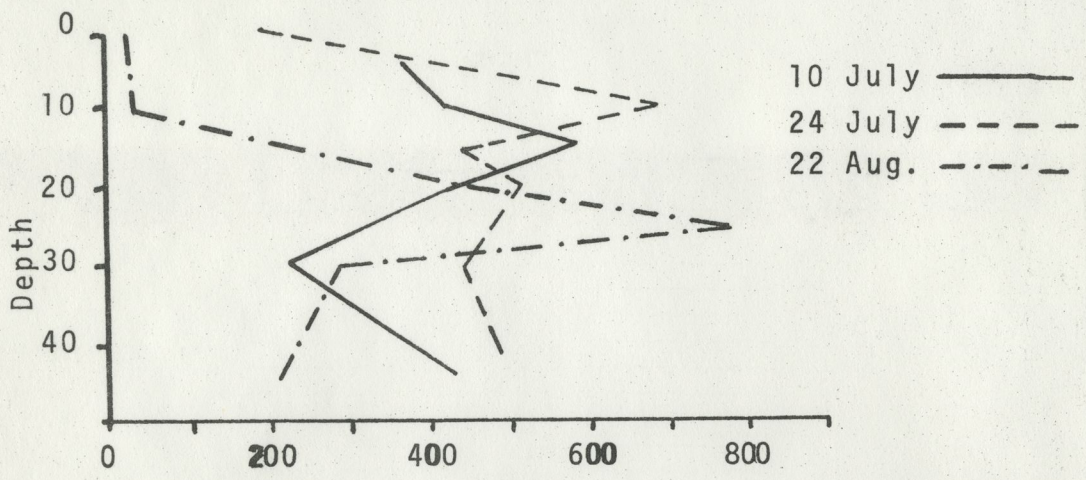


Fig. 48. Total viable bacteria in a vertical profile at Station 4, Las Vegas Bay, Lake Mead, 10, 24 July and 22 Aug., 1972.

from 10-15m. On 24 July, maximum bacterial counts occurring at 10m and the biggest oxygen decrease again occurred from 10-15m. On 22 August, maximum bacterial counts were at 25m and the biggest oxygen decrease occurred between 10-15 m. At Station 14 on 22 August maximum bacterial counts occurred at 30 and 90m while the greatest decrease in oxygen was between 10 and 15m. Thus we see that bacterial maxima do not necessarily correspond to zones of maximal oxygen depletion. In addition while oxygen profiles at most stations throughout Las Vegas Bay (including Stations 4 and 14) are quite similar, bacterial counts at the two stations are very different.

In spite of the apparent lack of a direct cause-effect relationship between oxygen depletion and bacterial populations, one is left with the impression of some general, perhaps secondary relationship between the two phenomena.

One additional point made forcefully by our data on bacterial populations is that very large numbers of bacteria, including coliforms, are injected into Lake Mead daily from Las Vegas Wash. If a flow rate for the wash of 10^6 GPD is assumed, and this seems a rather conservative estimate, the number of coliforms delivered to the bay in 24 hours would reach the impressive total of 1.65×10^{12}. There are of course several important factors ignored or oversimplified by presenting simply a total number. Among these are 1) origin, human

or other, 2) continuity of numbers over a day, 3) biological and physical rates of decay, 4) settling rate in relatively static water, and 5) actual flow rate. However, in view of the USPHS standard for drinking water of 2.2 coliforms per 100 ml water as acceptable, and 4 requiring immediate remedial action, the datum of 440 coliforms per ml flowing water implies a possible public health hazard.

The fact that numbers of bacteria are greatly reduced as one moves out the bay suggests that the Las Vegas Wash may be a primary source of bacteria occurring in the lake. However, other sources must not be overlooked. A considerably more thorough examination of bacterial population ecology in Lake Mead is clearly indicated.

A report by FWPCA (1967) discussed bacteria, algae and nutrient concentrations in Las Vegas Wash and Lake Mead. Their samples appear to have been taken entirely from surface waters. Coliform densities at our Stations 16, 1, 4, and 9 were reported for May 1966 as means of 862, 44, 4 and 2 per 100 ml respectively. Our counts of water samples collected on 22 August, 1972 from about the same localities were 44,000, 1400, 500 and 0 per 100 ml respectively. This suggests that coliform bacterial populations may have increased since 1966. However, the fact that we know almost nothing of temporal and spatial variability of bacterial populations in Lake Mead prevents us from developing very convincing conclusions regarding

the point. It is possible to point out, however, that the 1972 data definitely indicate that Las Vegas Wash at North Shore Road and the area of Las Vegas Bay near Station 1 exceed the generally accepted standard of 1000/100 ml for coliform densities in water suitable for water contact sports. The drinking water standard of 4/100 ml requiring immediate remedial action is of course far exceeded out past Station 4.

Figures 49-51 summarize data on vertical distribution of nutrients at Station 4 on 10 July and 22 August and Station 14 on 22 August. Nitrite and nitrate nitrogen increases sharply from 10-15 m at Station 4 and from 10-20 m at Station 14. Ammonia shows a sharp increase at Station 14 at 20 m. Phosphorus at Station 4 also shows vertical variation with peaks at 15 and 30 m on 10 July and at 10 and 25 m on 22 August. At Station 14 phosphorus peaks occur at 10, 20 and 60 m on 22 August. Alkalinity and pH respectively show increases and decreases below 10 meters that in general correspond to vertical variations of other parameters measured.

Vertical distribution of zooplankton was also examined on 22 August at Stations 4 and 14. Samples were taken with a Clarke-Bumpus plankton net at 10 m intervals to 50 m at Station 14. Fig. 52 presents data as dry wt/m^3 at the various sampling levels. It is evident that the most dense zooplankton populations occur at 30 m at Station 14 where also we were able to identify more different kinds of plankters

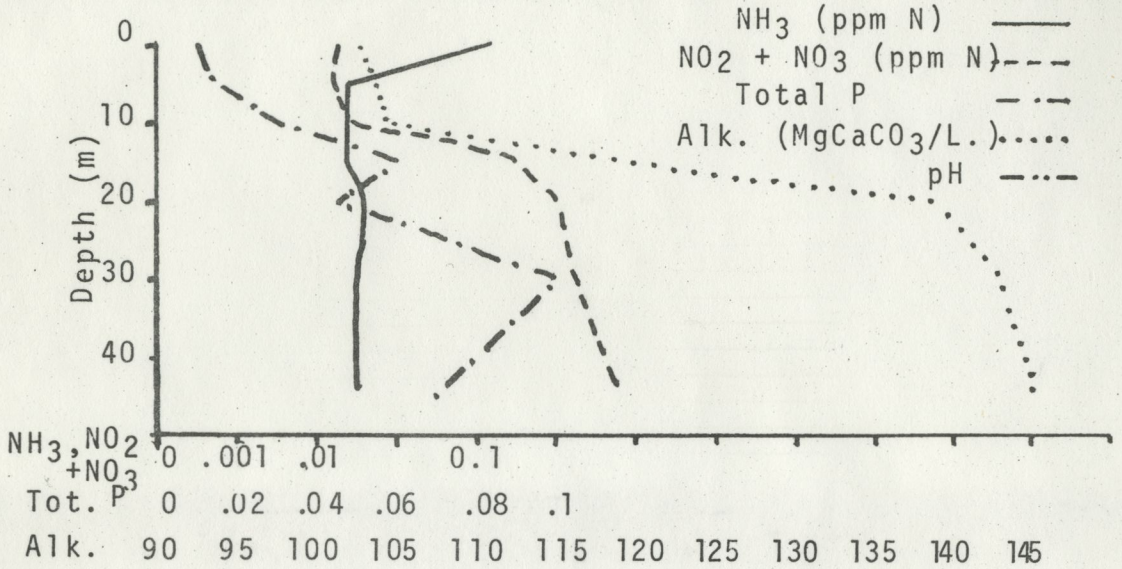


Fig. 49. Vertical variation in nitrogen, phosphorus and alkalinity at Station 4 on 10 July, 1972.

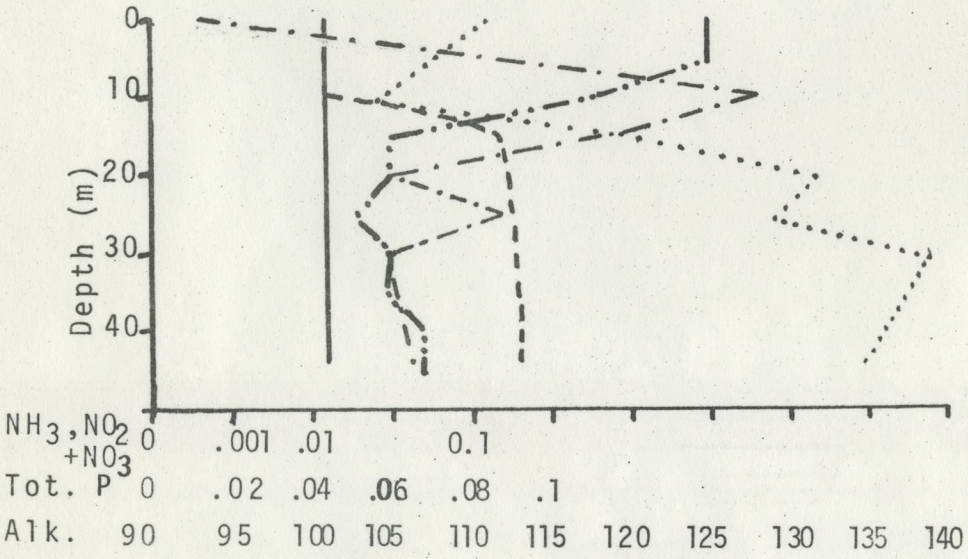


Fig. 50. Vertical variation in nitrogen, phosphorus and alkalinity at Station 4 on 22 August, 1972.

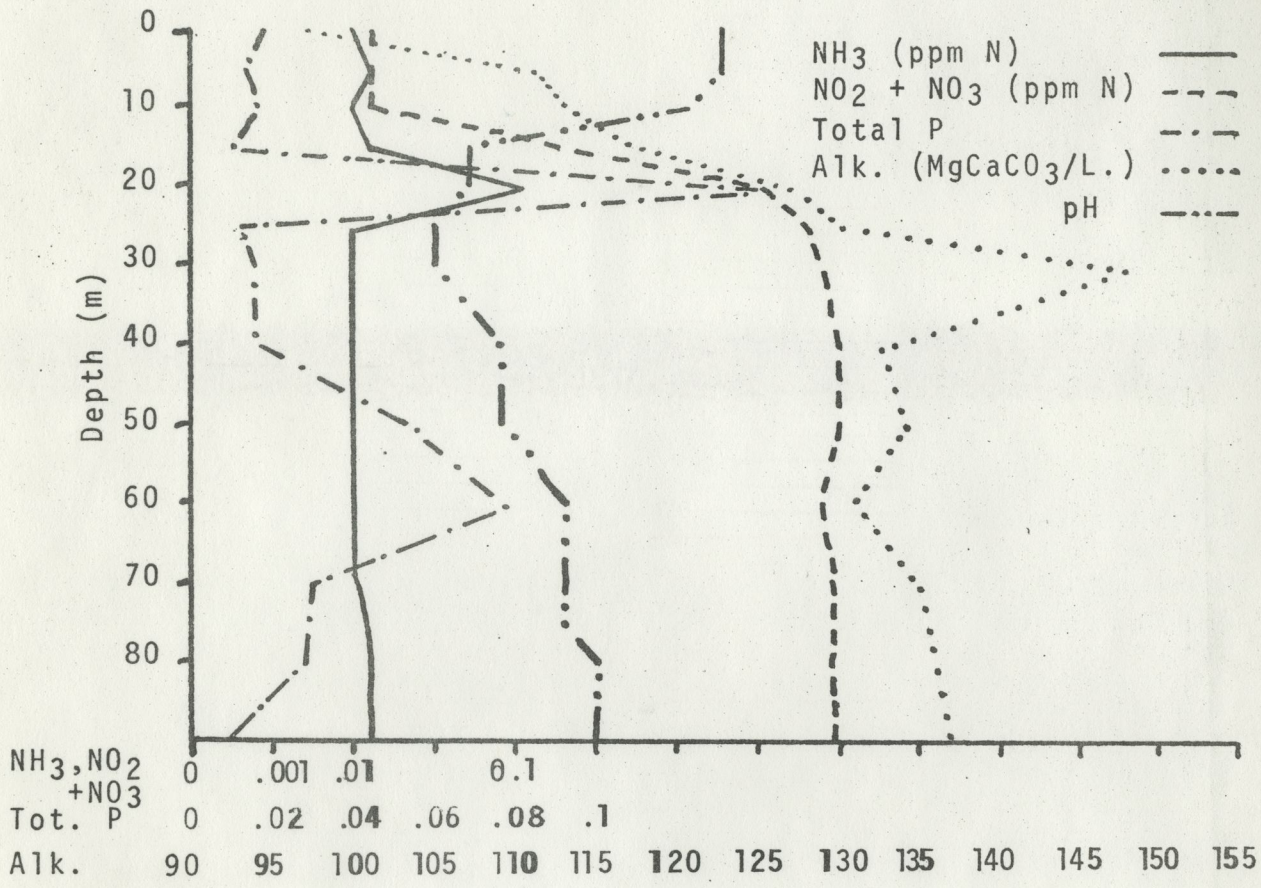


Fig. 51. Vertical variation in nitrogen, phosphorus and alkalinity at Station 14 on 22 August, 1972.

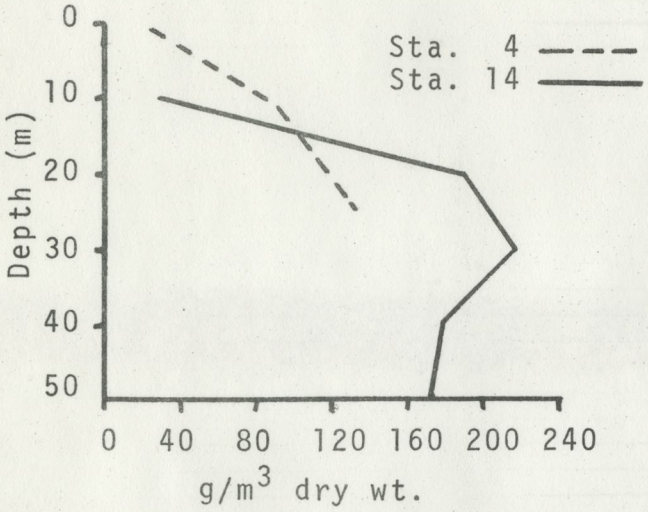


Fig.52. Vertical distribution of net plankton biomass.

than at other levels. At Station 4 on the other hand, the increased weight indicated at 25 m was largely due to debris collected in the plankton net and fewer plankters were identified at that level than in shallower collections.

It became apparent in early July that distribution of shad as indicated by sonar tracings closely coincided with the zone of oxygen depletion. This relationship was examined more closely on 20-21 July and again on 22-23 August at Station 4. Data for these periods are presented in Figs. 53 and 54 and Table 39. On 20-21 July there is an apparent correlation between the distribution of shad and the depth at which the greatest O_2 decrease occurs. During the daylight hours the shad are dispersed mainly from 10-20 meters. The decrease in O_2 at 1151 hours from 10-15 meters is 2.0 ppm, from 15-20 meters 2.5 ppm, a total of 4.5 ppm from 10-20 meters. This we suggest is the typical daytime pattern. Note however, that in the afternoon a greater percentage of the total depletion occurs from 10-15 m.

A gradual upward movement of shad apparently began about 1500 hours, but the pronounced change is seen at 2018 and 0350 hours. Most of the shad had moved up and were located mainly from 10-15 meters at 2018 and 0350 hours. Note also that between the hours of 2018 and 0315 the overwhelming percentage of the oxygen depletion occurred between 10-15 m yet the total magnitude of depletion occurred between 10-20 m remained surprisingly constant throughout the day. The pattern of oxygen

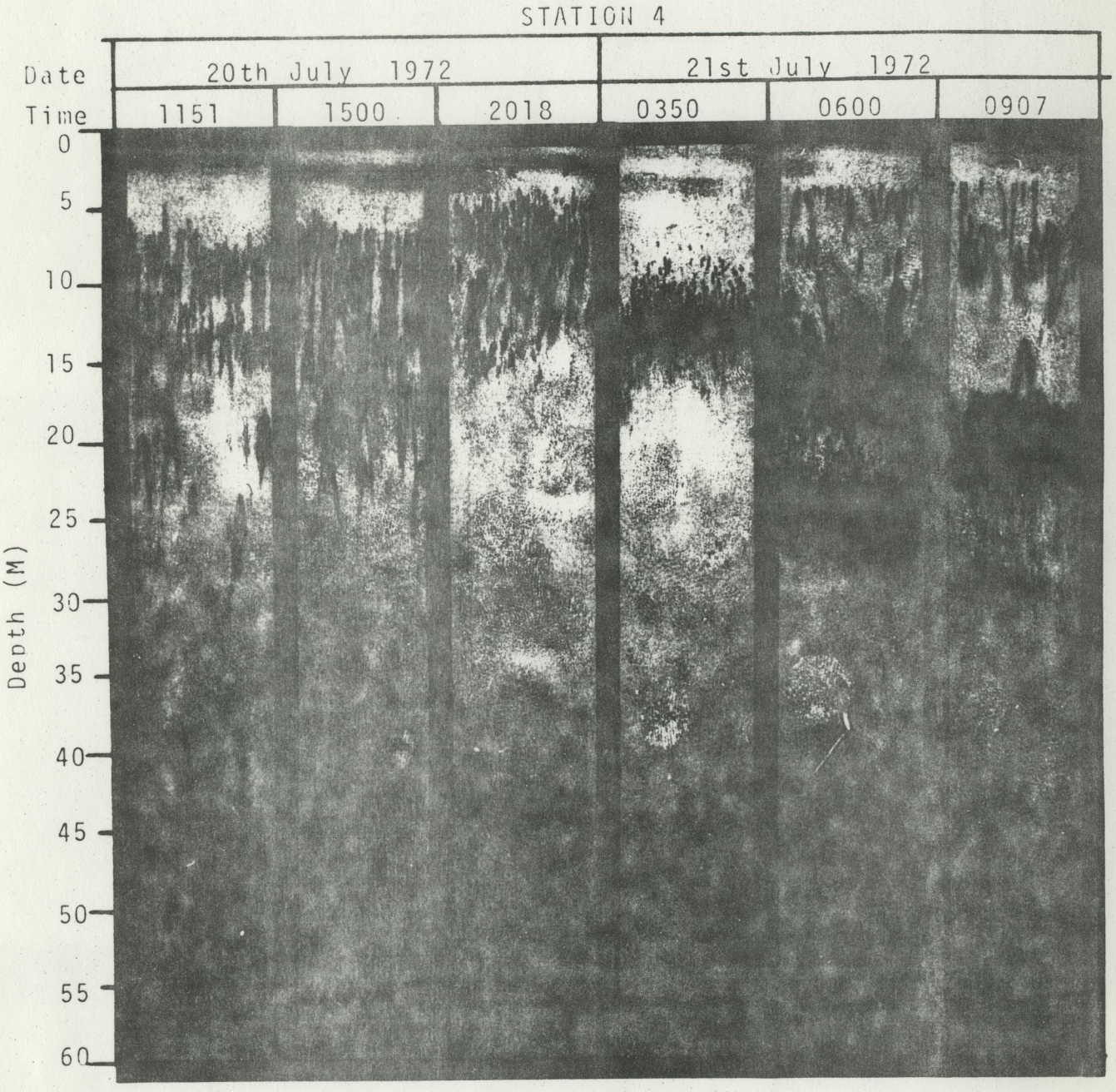


Fig. 53. Echogram of diurnal variations of fish distribution at Station 4, July 20-21, 1972.

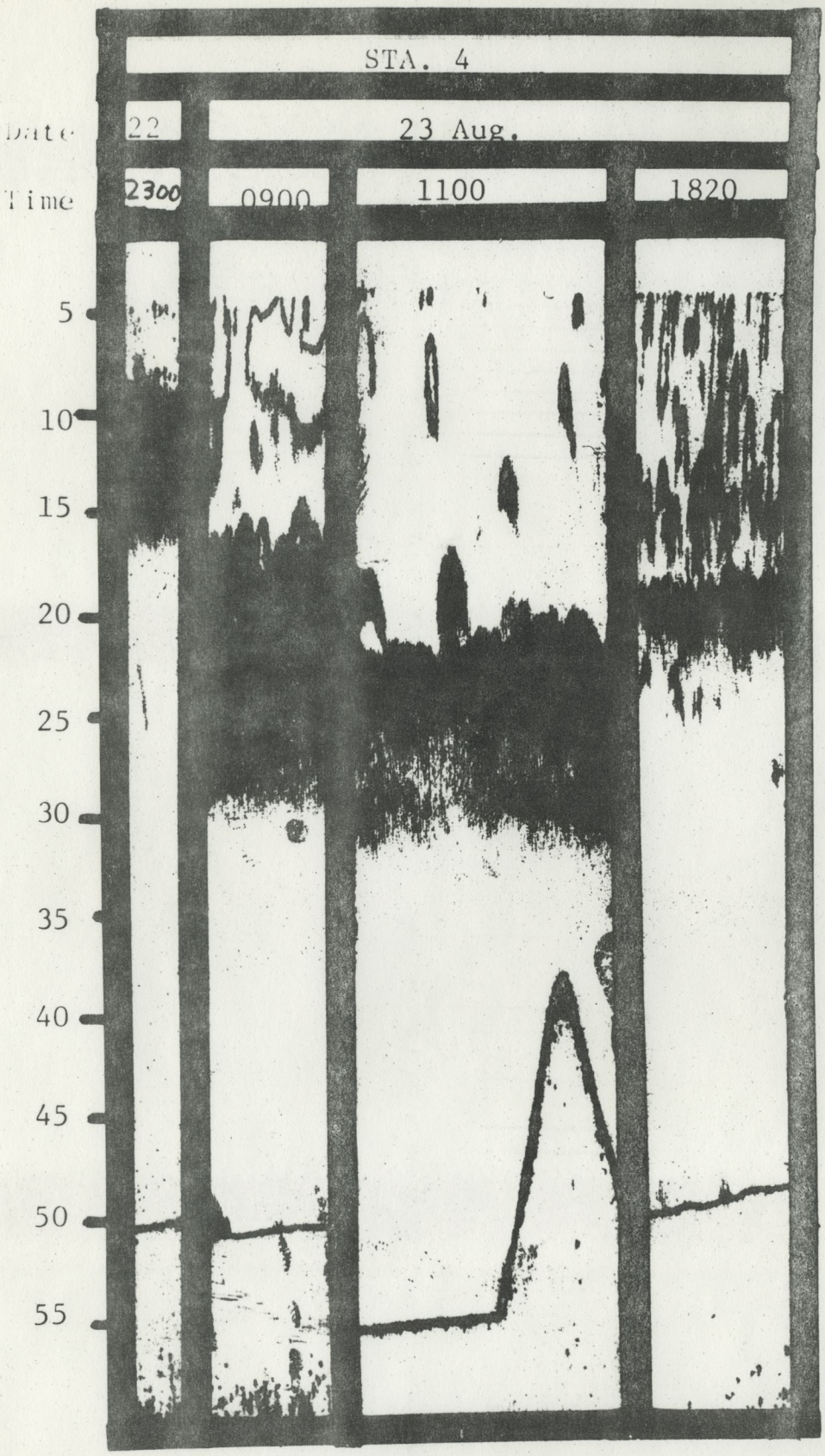


Fig. 54. Echogram of diurnal variations of fish distribution at Station 4, August 22-23, 1972.

Table 39. Magnitude of oxygen depletion (ppm) between indicated depths at Station 4, Las Vegas Bay, Lake Mead, 1972. The numbers indicate the magnitude of oxygen decline in ppm. For data on oxygen concentrations refer to Table 34 and the appendix.

		Depth (m)						Depth (m)			
Date	Time	10-15	15-20	10-20	Date	Time	5-10	10-15	15-20	5-20
20 July	1151	2.0	2.5	4.5	23 August	1120	3.1	4.2	0.3	7.6
20 July	1500	3.2	1.7	4.9	23 August	1820	3.2	4.5	0.3	8.0
20 July	1805	3.5	1.5	5.0	22 August	2300	0.9	6.7	0.6	8.2
20 July	2018	4.4	0.5	4.9	23 August	0820	3.0	4.2	0.8	8.0
20 July	2340	4.3	0.7	5.0						
21 July	0350	3.5	1.3	4.8						
21 July	0600	2.9	2.4	5.3						
21 July	0907	2.8	2.5	5.3						

depletion returned to the "daytime" condition at 0600 hours.

On 22 August the relationships were slightly different with the major shifts occurring at 5-15 m rather than at 10-20 m. Again, however, the "daytime" distribution of oxygen depletion was relatively evenly spread over a 10 meter interval, a significant shift occurred at night when most fish and perhaps also zooplankton became densely concentrated at 10-15 m where the overwhelming percentage of oxygen decline occurred (Table 39).

The echograms for both 20-21 July and 22-23 August suggest behavioral differences between daylight and darkness for threadfin shad. An inverted V on the echogram indicates a school of shad while single marks indicate individual fish which may be any species. The echograms clearly indicate that shad are schooling usually during daylight. Apparently during darkness the schools break up and the fish become heavily concentrated in a narrower zone. Johnson (1969) indicated that this general pattern occurred in the Salt River reservoirs in Arizona also and further that feeding activities increased at night. If feeding by shad occurs in Lake Mead at night it is possible that metabolic activity would also increase somewhat. This increased metabolic activity concentrate them in the zone that our echograms show shad to be occupying at night.

Somar echograms were verified by fish trapping to insure that the sonar reflections, believed to be shad, were actually

shad and not some other organism. The fish traps were simple funnel type traps equipped with two 6-volt lights and were constructed from 1/4" mesh galvanized wire and were suspended by a rope from a sampling buoy. The traps were not successful when lights were not used. The trapping periods were kept as close to 12 hours as possible.

The results of all trapping periods are summarized in Table 40. It should be noted that all shad captured were young of the year fish generally ranging in size from 25-50 mm total length. The results indicate that few shad are present at Station 2; this was the case throughout the bay in waters shallower than 20 meters. Station 2 is 12-14 meters deep depending upon the lake level. While oxygen does decline from surface to bottom at Station 2, the magnitude of decline corresponds approximately to the "daytime" conditions at deeper stations where shad occur. Magnitude of oxygen decline at Station 2 never was as great as commonly measured for "night-time" conditions elsewhere. Significantly Station 2 is in the inner bay where one would expect the most severe oxygen depletion if it were entirely attributable to eutrophication caused by input from Las Vegas Wash.

Numbers captured at Stations 8 and 14 appeared similar on 4-6 September. On 16-17 September traps were set at 5, 10, and 20 m at Station 8. Results showed that 88% of the shad captured were taken at 10 m. This corresponded closely with conclusions made from echograms. We, therefore, concluded that

Table40. Results of a series of 12 hour fish trapping periods at Stations 2, 8 and 14.

Station	Date	Times	Depth (m)	# of shad captured	$\overline{X}$ length (mm)	$\overline{X}$ weight (gms)	% of Population
2	18-19 Sept. '72	1900-0730	12	10	44.4	1.0	-
8	4-5 Sept. '72	2030-0830	10	111	35.3	.40	-
14	5-6 Sept. '72	2000-0800	10	76	39.5	.57	-
8	16-17 Sept. '72	1900-0700	5	24	40.0	.90	5.6
8	16-17 Sept. '72	1900-0700	10	377	41.0	.70	88.3
8	16-17 Sept. '72	1900-0700	20	26	39.3	1.1	6.1

generalizations regarding shad distribution made from echograms had reliability.

The horizontal and vertical distribution of shad in the bay was measured with sonar throughout the year. Figure 55 shows the typical distributional pattern of shad on various dates. The echogram for 7 May is representative of the entire winter and early spring and shows the presence of very few fish. The echogram for 10 July is typical of the summer months with most of the shad occurring in the epilimnion above the thermocline; 24 October and 6 November are typical of the fall pattern. It is interesting to examine what happens in the fall when thermal stratification begins to break, and the thermocline gradually sinks. For instance on 24 October the temperature change occurs mainly from 25-35 meters (Fig. 47), and as Figure 55 shows most of the shad are also located from 25-35 meters. O_2 depletion also became pronounced at 20 meters and reached a low at 35 meters. The same situation existed on 6 November, except that the temperature change and shad layer had dropped to 35-45 meters and as Fig. 47 reveals O_2 depletion also was pronounced at those depths.

The obvious question is why do shad follow the thermocline as it gradually drops. One possible explanation would be because of a temperature preference. But this seems unlikely since during each period (10 July, 24 October, and 6 November) the temperature at the thermocline is different.

An alternative suggestion is that at the thermocline there

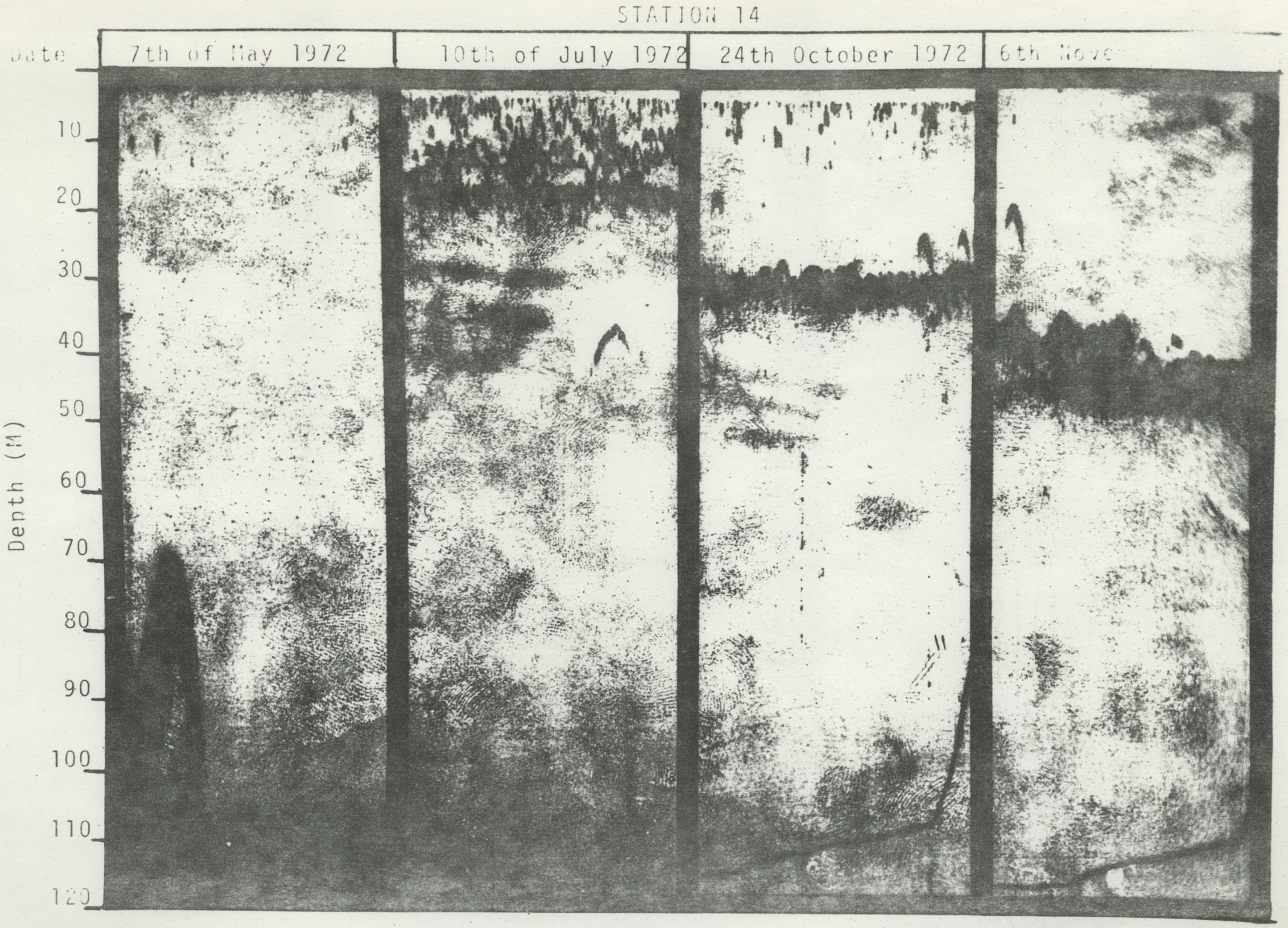


Figure 55. Seasonal chanfes in fish distribution recorded by sonar, 1972.

is a slight density change which provides a surface through which sinking rates of organic debris are greatly slowed, essentially concentrating them on a horizontal plane throughout the lake. Perhaps the plankton populations in the epilimnion do not provide a sufficient large, preferred food source to supply the requirements of the shad population. Shad therefore congregate near the thermocline, eating the suspended organic material which collects there. At this stage of analysis this appears to be a valid hypothesis for two reasons: 1) shad utilize debris in their diet to a large degree (Deacon et. al., 1971); 2) few shad were encountered at Station 2 where there is a higher surface plankton population than occurs at the outer stations. Station 2 however does not thermally stratify.

While the reasons for concentration of shad near the thermocline may be subject to some question, the fact of their concentration there is not questionable. The effect of crowding of such a large biomass into a relatively small volume must be considerable. Our measurements, summarized in Figs. 47-51, show that in the zone of shad concentration the following phenomena occur: 1) oxygen is depleted, 2) viable bacteria show a marked increase, 3) coliform bacteria show an increase, 4) nutrients (NH_3, NO_2 and NO_3, dissolved P and total P) show an increase, 5) alkalinity increases, and 6) pH decreases.

The general hypothesis emerging from these data is that threadfin shad concentrate at the thermocline primarily to feed

on the accumulated organic debris at that location. Secondarily they may be attracted to that area by a combination of temperature and illumination preference. The concentration of biomass at a single level in Lake Mead results in production of relatively large quantities of fecal and metabolic wastes which together with the organic debris accumulated there because of the density discontinuity provides substrate for growth of bacteria. The summation of the biological activity at or near the thermocline causes oxygen depletion and results in an increase in nutrient levels. The condition is most severe in Las Vegas Bay because of the added influence of the nutrient and bacteria-rich waters of Las Vegas Wash. If this hypothesis is correct one would expect a general relationship between shad density and magnitude of oxygen depletion in Lake Mead. A few samples from Gregg Basin, Temple Basin, Virgin Basin, Overton Arm and Boulder Basin suggest that this general relationship does exist. Other hypotheses could perhaps be developed to explain or interpret the data. The one presented here seems most consistent with the data at this time. Particularly troublesome is the role played by impoundment of Lake Powell. If the limited data for that period are correct the effect of impoundment must have been both marked and immediate.

DISCUSSION

This study was motivated and funded by a desire to define the general biological condition of Las Vegas Bay of Lake Mead and attempt a prediction of the effects of various alternative manipulations of Las Vegas Wash. Early in the study it was apparent that the most probable manipulation of Las Vegas Wash would be to export much of the water out of Las Vegas Valley. The discussion below is therefore directed toward the two main objectives with special emphasis on the effects of eliminating much of the inflow from Las Vegas Wash. Because of the continual need for assessment of the effects of manipulation and the continually changing conditions in the lake, it is apparent that continous study of Lake Mead and the lower Colorado system is essential.

Numerous indices have been proposed to aid in classifying waters in a way that permits comparison of various waters and assessment of changes with time. These indices use standing crops, nutrient ratios, rates of production, presence or absence of indicator organisms, physical-chemical characteristics of the waters or morphological features of the lake basin as means of classification.

Lund (1969) points out that in general the quantity of phytoplankton present at a given time is what is objectionable regardless of how long it took to produce the material. Mean numbers of phytoplankton for inner, middle and outer portions of Las Vegas Bay are indicated in Fig. 56. Yearly maxima for

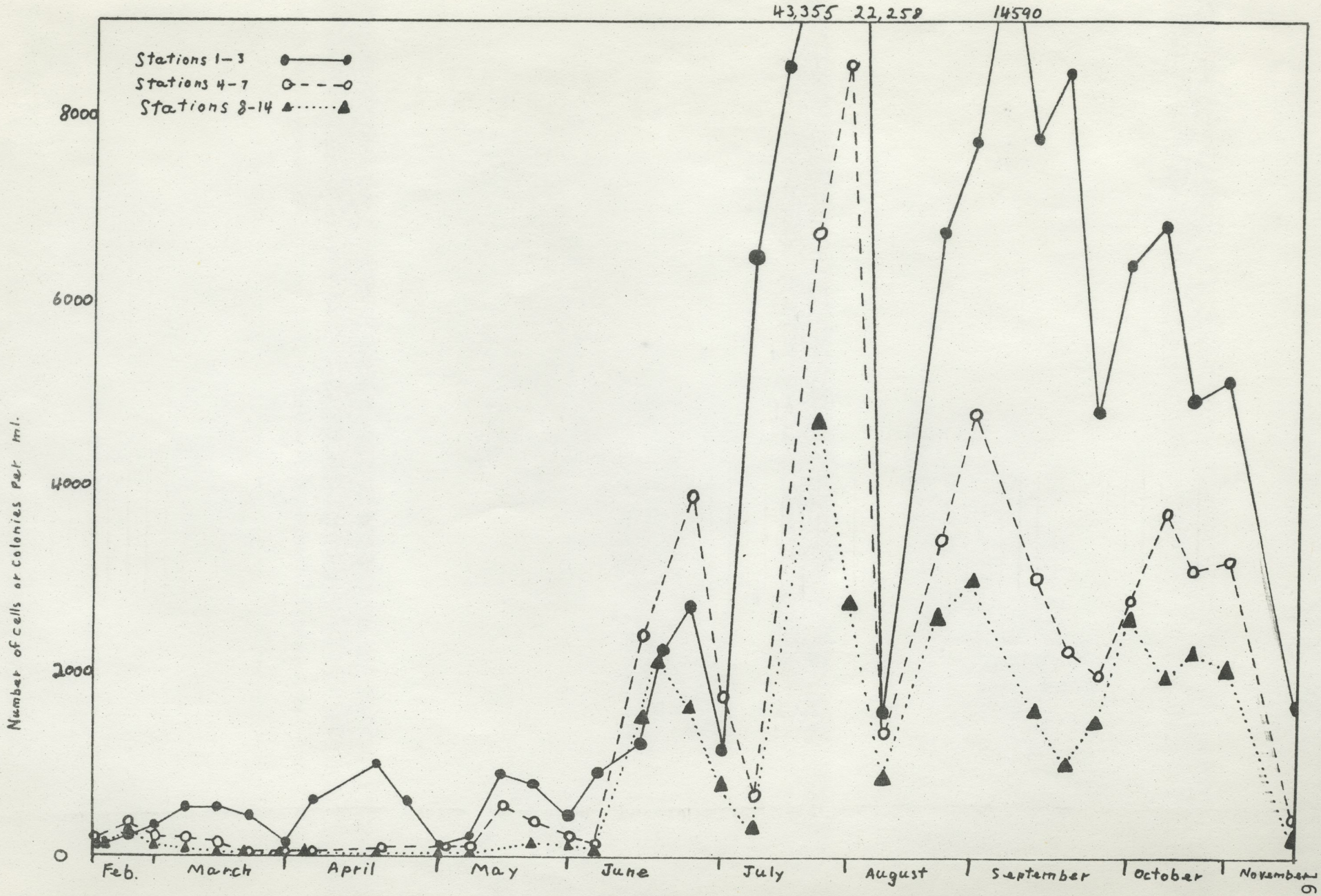


Fig. 56. Mean number of cells or colonies of phytoplankters per ml in the inner, middle and outer portions of Las Vegas Bay, Lake Mead.

the three areas were about 43000, 8500 and 5000 per ml respectively, while minima were about 140, 66 and 50 per ml, respectively. Mean numbers exceeded 5000 per ml at the middle bay stations for a two week period in July. For inner bay stations counts exceeded 5000 per ml during most of July, August, September and October. While firm statements regarding undesirable numbers of phytoplankton have not been made, Lund (1969) points out that when diatoms exceed 1000/ml they can become troublesome in a waterworks. Lackey (1949) arbitrarily defined a bloom as 500 cells per ml. Using that criterion Mackenthun (1969) pointed out that large areas of Lake Michigan, especially along the eastern shore, contained blooms of phytoplankton during the summer of 1962 and Beeton (1965) reported counts of 450-12000 plankters/ml with a mean of about 4500/ml. West and Mackenthan (1966) also found blooms of 1000 to nearly 4000 organisms per ml in Lake Tahoe at the Tahoe City boat harbor during April and July 1962. By contrast Mackenthun (1969) also reported phytoplankton counts ranging between 600 and 212000 per ml from Lake Sebasticook, Maine where a pollution problem clearly existed. Lund (1969) reports diatom maxima from several English lakes ranging from less than 100 to 40000 per ml. Funk and Gaufin (1971) report more than 4000 cells/ml for bloom producing species in the Viva Naughton, Wyoming.

This small sample indicates the considerable variability involved in making judgements based solely on numbers of plankters. Nevertheless it is apparent that Las Vegas Bay does not

contain plankton populations as dense as those occurring in severely polluted lakes but does contain populations in the inner bay during the summer that compare with densities considered to indicate eutrophic conditions. The plankton population densities of the middle and outer bay on the other hand serve to emphasize the reality of Rohlich's statement in his summary remarks following the 1967 International Symposium on Eutrophication, " . . . Furthermore, we need better documentation of the numbers and species of algae that are considered a nuisance."

Addition of nutrients has long been recognized as one means of increasing primary productivity of a water body. Thomas (1969) summarized much of the information available on nutrient addition in European lakes and developed a scheme of eutrophication based on nutrient ratios. Moreover he pointed out that oligotrophic lakes on which man has had little or no influence all have phosphate as the limiting nutrient and that the presence of free nitrate ions throughout the year indicates the lake's primitive stage. As phosphate input increases the algae are able to use larger proportions of the available nitrate until finally nitrate may become the limiting nutrient. Using the scheme of eutrophication proposed by Thomas (1969) for data gathered at both Stations 1 and 14, Las Vegas Bay of Lake Mead falls into his oligotrophic-mesotrophic category -- the first step toward eutrophication in an oligotrophic lake.

Data presented in Table 41 indicate that conditions at Station 1 are clearly more eutrophic in character than at Station 14. Many nutrients occur in higher concentration at Station 1. In addition the ranges of concentrations for ammonia, nitrogen, dissolved P, Cl, SO_4, Mg, SiO_2, O_2 pH, and conductivity are greater at Station 1 than at Station 14. This information plus the fact that data presented in Table 31 indicate algal growth at Station 1 to be primarily nitrate-limited points consistently to the greater eutrophication of the inner bay than elsewhere in Las Vegas Bay. Data in Table 41 suggest that nutrient limitation to algal growth at Station 14 may involve either nitrogen or phosphorus at different times of the year.

Edmondson (1969), reviewing eutrophication in North America, points out that few limnological investigations have been of long enough duration to provide continuous information on the process. Some information on nutrient balance is however of interest. Wintertime maxima for inorganic nitrogen of 1.2 mg per liter, for dissolved phosphorus of .011 mg per liter and for total phosphorus of .05 mg per liter have been recorded for Lake Sebasticook, Maine. Some reservoirs on the Missouri River develop total phosphorus concentrations of more than 1 mg per liter. Maximum concentrations of phosphorus and nitrogen develop during the winter in Lake Washington and were about .06 and .55 mg per liter respectively. By comparison maximum concentrations of phosphorus and nitrogen

Table 41. Maximum and minimum values (ppm, except where otherwise indicated) for various physical and chemical parameters at Stations 1 and 14, Las Vegas Bay, Lake Mead, 1972.

	Station 1		Station 14	
	min.	max.	min.	max.
$NO_2 + NO_3 - N$	.01	.02	.02	.09
$NH_3 - N$	.03	.11	.02	.07
$CaCO_3$	85	108	84	110
PO_4 - dissolved P	.02	1.0	.00	.05
PO_4 - total P				
HCO_3	113	158	120	162
CO_3	0	0	0	0
Cl	103	125	97.0	99.5
SO_4	326	377	312	337
F	.32	.37	.31	.34
Na	113	128	102	112
K	5.03	6.25	4.0	5.8
Ca	82.1	84.4	76.2	90.2
Mg	32.8	36.6	30.2	32.2
SiO_2	4.2	10.2	7.8	8.8
TDS	841	841	814	814
Oxygen (surface)	8.1	17.4	7.2	12.2
Oxygen (at min. point in vertical profile)				
pH	7.9	8.8	8.1	8.6
Temperature	8.5	28.3	11.0	27.0
Conductivity (micromlohs-cm)	700	2100	700	1800

at Station 14 of Las Vegas Bay was .05 and .09 and in the head of Las Vegas Bay 1.0 and .02 mg per liter, respectively. It seems apparent that by comparison with other eutrophic lakes in North America, Las Vegas Bay contains relatively high phosphorus and relatively low nitrogen.

The study of algal growth potential (FWQA, 1970) conducted in Lake Mead indicated that algal growth was primarily phosphate-limited. Our evidence suggests nitrate limitation at Station 1. Unfortunately our techniques were too crude to provide indications of limiting nutrients at Station 14. The suggestion we are left with is that nutrient input near Station 1 provides sufficient quantities of phosphorus to permit algal growth to proceed to the point of utilization of available nitrogen until it becomes limiting. Farther into the bay and lake following biotic and abiotic removal of influent phosphorus, that element again becomes limiting as is the usual situation. The samples for the FWQA study were taken farther into the bay than Station 1 and therefore reflect the condition of phosphorus limitation.

Hutchinson (1967) and Rawson (1956) discuss the problems of using phytoplankton genera as indicator organisms in the trophic classification of lakes. They each suggest certain genera that have been used meaningfully somewhere in the world (Hutchinson, 1967) or in lakes in western Canada (Rawson, 1956) to indicate the trophic position of the lake. Table 42 summarizes their data and compares dominant genera in Lake Mead

Table 42. Dominant phytoplankton genera occurring in Lake Mead compared with indicator organisms as classified by Hutchinson, 1967.

Oligotrophic	Mesotrophic	Eutrophic	Lake Mead
Asterionella*	Ceratium*	Anabaena*	Anabaena
Botryococcus	Fragilaria**	Anacystis	Carteria
Ceratium	Glenodinium	Aphanizomenon*	Chlamydomonas
Cosmarium	Melosira**	Arthrospira	Colonial Green
Cyclotella	Pediastrum**	Asterionella	Cyclotella*
Denticula	Peridinium	Coelosphaerium**	Fragilaria
Dinobryon*	Staurastrum**	Euglena	Glenodinium
Fragilaria	Stephanodiscus**	Gloeotrichia	Navicula
Gloeocystis		Lepocinclis	Phacotus
Halotheca		Lyngbya	
Mallomonas		Melosira	
Melosira*		Microcystis**	
Oocystis		Nodularia	
Peridinium		Oscillatoria	
Rhizosolenia		Pediastrum*	
Sphaerocystis		Scenedesmus	
Staurastrum		Staurastrum	
Staurodesmus		Stephanodiscus	
Synedra		Synedra	
Tabellaria*		Trachelomonas	
Uroglena			

* Classified here also by Rawson (1956)

** Classified here by Rawson (1956) but not by Hutchinson (1967)

with their classification. We find that one of the nine genera (Anabaena) to exert clear dominance in Lake Mead at some time during the year is recognized by both Hutchinson (1967) and Rawson (1956) as an eutrophic indicator. Anabaena was dominant or at least prominent in the plankton from late July through October. Glenodinium, listed by Hutchinson (1967) as a mesotrophic indicator, was prominent in the inner and middle bays (Table 43) from late July through October. The genus also occurred in the outer bay. Fragilaria is included by Hutchinson (1967) as a genus that can become very abundant in oligotrophic lakes of central Europe usually having Cyclotella as the dominant form. Fragilaria is regarded by Rawson (1956) to be a mesotrophic indicator in western Canada. He points out that Cyclotella, often found in highly oligotrophic lakes of Europe, is not dominant or even particularly common in lakes of western Canada. Cyclotella is proposed by Hutchinson as an indicator of oligotrophic conditions when it occurs as a dominant form. The genus occurred as a co-dominant with Anabaena in Lake Mead from about mid-July through October. Interestingly Cyclotella tended to maintain dominance over Anabaena in the inner bay while the opposite situation most frequently occurred in the middle and outer bays. Colonial green algae were dominant from mid-June through early July.

The other genera to achieve dominance or prominence in Las Vegas Bay are not included as indicator organisms by Hutchinson (1967) or Rawson (1956).

Table 43. Dominant phytoplankton genera (more than 500 per ml) occurring in Las Vegas Bay of Lake Mead at some time during 1972.

	Inner Bay	Middle Bay	Outer Bay
Carteria	X	X	
Anabaena	X	X	X
Glenodinium	X	X	
Cyclotella	X	X	X
Colonial Green	X	X	X
Chlamydomonas	X	X	
Navicula	X	X	X
Phacotus	X		
Fragilaria	X	X	

This analysis leaves us with the impression that Lake Mead, based on indicator organisms, has characteristics of both eutrophic and oligotrophic waters and therefore is probably best regarded as mesotrophic. It would be useful to have concurrent data from elsewhere in the lake as a means of better placing Las Vegas Bay in perspective.

Primary productivity has been used frequently and increasingly as an index of eutrophication. Table 44 summarizes data from numerous sources. Rodhe (1969) develops useful generalizations regarding the utility of this technique and proposes a tentative classification of lake types based on measurements of primary productivity. He points out that comparisons between biomass of producers and rates of daily productivity indicate in general a direct relationship despite wide variations in certain cases. This general relationship he believes justifies the use of phytoplankton productivity in place of phytoplankton quantity for determining the trophic classification of lakes. In essence Rodhe is proposing that productivity measurements be used to give additional insight into understanding lake ecosystems. He is careful to point out however that primary production at a station may fluctuate considerably from day to day because of the well-known patchiness of phytoplankton distribution and because of wind action and that seasonal variations may also be very large. Therefore a thorough study throughout the year is essential if one is to achieve a reliable assessment using this technique. For these reasons few lakes have been

Table 44. Primary productivity in lakes from various areas of the world.

Location	Max. carbon fixation ($g/m^2/day$)	Max. dissolved P (mg/l)	Tot. P	Max. inorganic N (mg/l)	Secchi disc (m) max.	Secchi disc (m) min.
Lake Washington	6.09	.06		.55		0.7
Lake Sebasticook		.011	.05	1.2	2.6	0.9
Lake Winnisquam	0.32				7.1	
Lake Erken, Sweden	2					
Lake Esrom, Denmark	2					
fertilized Danish lakes	6					
Lake Mead	3.2	1.0		.09		
Lake Viva Naughton*	1.2					

*estimated from data expressed as mg $C/m^3/hr$ -- Funk and Gaufin

evaluated using this technique.

Lake Mead was the subject of a study by Everett (1972) in which an assessment of primary productivity was made. The study resulted in Everett concluding that " . . . the ppr values have moved the lake into a polluted eutrophic state." Earlier reports and comments made by Everett during the course of his investigations indicated that he had shown Lake Mead to be "more eutrophic than Lake Erie" and that he expected conditions to deteriorate to the point of causing massive fish kills unless corrective action were taken soon to ameliorate the pollution originating from Las Vegas Wash. Since these conclusions appear to be somewhat at variance with ours we must attempt to reconcile them.

On five occassions during the year Everett made measurements of primary productivity at eight stations. At each station, single samples of water from 0, 1, 3, 5, 7, 10, 15 and 20 meter depths were incubated for a four hour period in an environment to which C^{14} had been added. Incubation, counting and other methods used were standard for this procedure. No attempt was made to assess the variability of the measurements at a single station, therefore it is impossible to evaluate the validity of the techniques used or their relationship to actual conditions in the lake. Similarly, since measurements at a single station were taken on a single day, it is impossible to evaluate the degree to which the measurements represent conditions in the area of the lake in which the stations were

located. The fact that only five measurements were made during the year does not permit evaluation of the reality of trends that might have been elucidated by more frequent sampling. In short, the uncritical approach to sampling used by Everett does not permit an evaluation of the reliability of his results. The fact that only one of his stations falls near our stations in Las Vegas Bay permits only an evaluation of his results at that one station by placing them in the context of the milieu of data we have collected.

The trend presented by Everett (1972) for Las Vegas Bay (his station was located in the middle bay) indicates that productivity proceeded from lowest to highest in the following pattern: January, April, June, November, September. Further, the ratio of these increases was about 1:1.5:2:3:5.3. Our data on phytoplankton numbers, while clearly measuring a parameter only generally related to primary production indicates that extreme variability is involved during the period referred to above. In the middle bay our average values (Fig. 56) indicate that a general pattern of increasing productivity for the months indicated above might be in the following order: April, January, November, June, September. Of perhaps greater significance is the demonstration that from 10 July to 8 August phytoplankton abundance in the middle bay increased and decreased about 24 fold or 2400 percent! Examination of the variability illustrated in Fig.56 and elsewhere in this report provides adequate documentation for understanding the fruit-

lessness of further attempts at reconciling our data with that developed by Everett (1972). His long intervals between sampling coupled with his failure to evaluate his methods and superimposed on the demonstrated variability of phytoplankton abundance in Las Vegas Bay forces us to conclude that Everett's data on primary productivity can serve no useful means of evaluating limnological conditions in Lake Mead. It would be helpful to develop reliable information on primary productivity in Lake Mead following the principles suggested by Rodhe (1969) mentioned earlier and coupled with an evaluation of the methods used.

In general Las Vegas Bay appears to be mesotrophic with the inner portion of the bay exhibiting eutrophic conditions. The special features of climate, basin morphology, characteristics of the drainage basin, management of water in the lake and interesting biological interactions superimpose an almost bewildering variety of conditions on the general characteristics. For example, warm temperatures speed up metabolic reactions causing higher productivities than would likely occur in more typically north temperate waters. The deep waters coupled with apparently complex currents maintain an oxygenated hypolimnion which in turn maintains an aerated sediment surface that therefore does not provide a nutrient source for the lake. The high salt content of the drainage basin coupled with high rates of evaporation produce increasing levels of total dissolved solids. Water withdrawals at Hoover Dam result in relatively rapid

flushing of lake waters. Nutrient cycling appears to depend almost entirely on basic input sources and cycling through limnetic organisms. Cessation of inflowing water from Las Vegas Wash will certainly mediate the eutrophic character of the inner portion of Las Vegas Bay. Very probably the same result would come from dispersing the effluent farther into the Bay or into Boulder Basin. Alternatively significant reduction of nutrients through improved treatment would also be reflected rapidly in lower algal populations.

The question of how much nutrient can be utilized by Lake Mead without degradation of water quality is only approximately approachable with present data. The observation that only in very restricted areas of the lake are conditions likely to permit nutrient regeneration from bottom sediments permits a somewhat easier solution to the question than would otherwise be the case. Pertinent information includes data presented by EPA (1971) in which inflow of phosphorus and nitrogen are shown to average about 370 Kg and 1470 Kg per day respectively. This nutrient load originates from sewage treatment plants and the Henderson industries. Daily nutrient output by the sewage treatment plants averages about 800 Kg and 1315 Kg of phosphorus and nitrogen respectively. The decrease in phosphorus from the primary input source to the mouth of the wash reflects uptake by plants. The increase in nitrogen reflects significant quantities contributed by seepage from the BMI ponds superimposed on the removal by plants. Thomas (1969)

suggests that a modest estimate of per capita phosphate phosphorus production from sewage is about 2.5 gm per day. Using that average one would expect about 750 Kg of phosphorus per day to be produced by the 300,000 people of Las Vegas Valley, not too far from the 800 Kg actually measured.

Oswald et. al. (1964) suggest that natural fresh waters are capable of assimilating about 9 Kg of oxidizable organic matter per acre per day. Vinberg, et. al. (1970) suggest that reasonable approximations for conversion of dry weight to P, N, and C respectively are .003, .02 and .4. Therefore if the phosphorus load is primarily derived from organic sources, Las Vegas Wash would be expected to contribute about 123,000 Kg per day of dry organic matter to Lake Mead. This load could be expected to require about 15,000 acres for assimilation. Lara and Sanders (1970) provide data regarding the area of the several basins of Lake Mead at various elevations. A reasonable approximation for Boulder Basin is 25,000 acres. This suggests that if dispersal were not a problem, Boulder Basin could be expected to assimilate about 225,000 Kg of oxidizable organic matter per day, or the equivalent of about 675 Kg of phosphorus. Flushing time of course would modify this assimilative capacity rather significantly by continuously removing some of the inflowing nutrients. It is therefore probably conservative to suggest that Boulder Basin is currently receiving about 50% of its assimilative capacity of phosphorus.

Because the nearly unique limnological features of Lake Mead cause the sediment surface to act essentially as a nutrient sink, reductions in quantities of nutrient inflow are likely to be reflected almost immediately in reductions of algal populations. It seems probable that maintaining a nutrient loading of less than about 185 Kg of P per day and less than about 735 Kg of N per day would alleviate the problems caused by algal abundance in Las Vegas Bay. This probability becomes a virtual certainty if hypolimnetic dispersion of the wash effluent into the main circulation of Las Vegas Bay is effected. In fact that practise would probably considerably increase assimilative capacity of the basin by taking advantage of the nutrient sink in the bottom sediments prior to nutrient cycling through the nekton.

Finally dominance of blue-green algae has long been associated with polluted lakes or lakes suffering eutrophication because of inflow of high quantities of nutrients. The failure of blue-green algae to develop overwhelming abundance in Lake Mead has been puzzling to some investigators who felt that other indicators of eutrophication suggested that Lake Mead should show a greater predominance of blue-green algae. King (1970) and Shapiro (1973) showed that blue-green algae are more efficient at obtaining CO_2 when it is present in low concentrations than are green algae. This suggests that when pH is high with the consequent shift of the CO_2 equilibrium reaction, blue-green algae should predominate if the nutrient concentrations

are sufficiently high. In fact, Shapiro (1973) indicated that blue-green algae are more efficient at utilizing phosphorus than are green algae. Since they are also nitrogen fixers their supply of macro-nutrients is virtually assured. Thus as nutrients are added to lakes, productivity can be expected to rise until free CO_2 disappears and bicarbonate CO_2 must be utilized. This brings on a rise in pH and the advantageous CO_2 uptake kinetics of blue-green algae allows them to dominate. This process apparently did not occur in Lake Mead, thus explaining why troublesome blue-green algal blooms have not occurred.

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